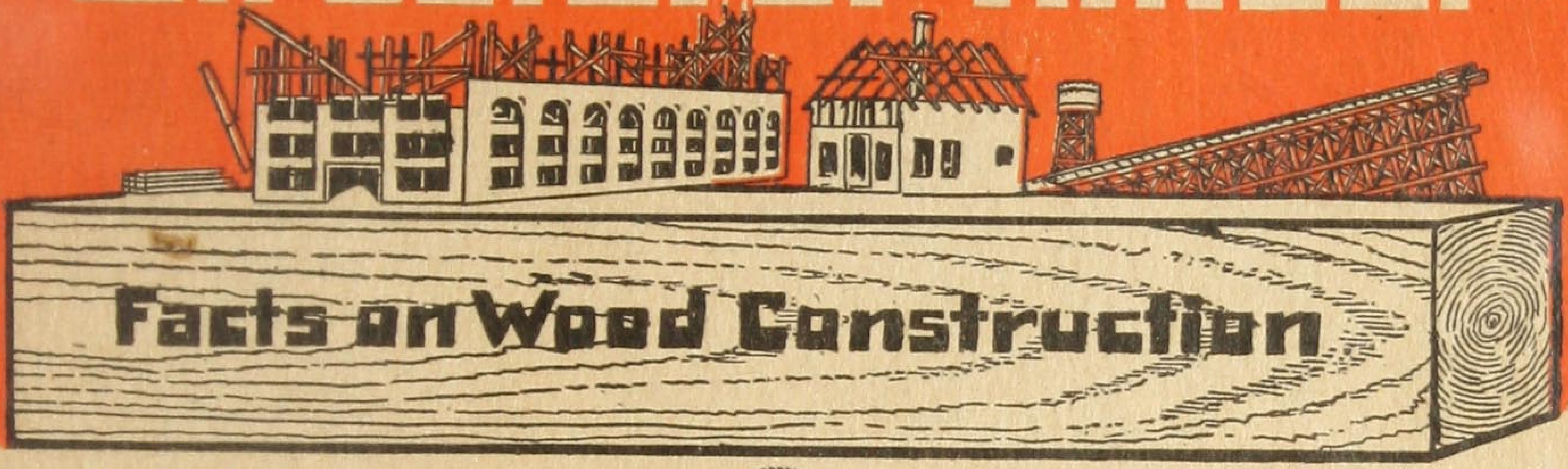
Engineering Bulletin No 2. May, 1916

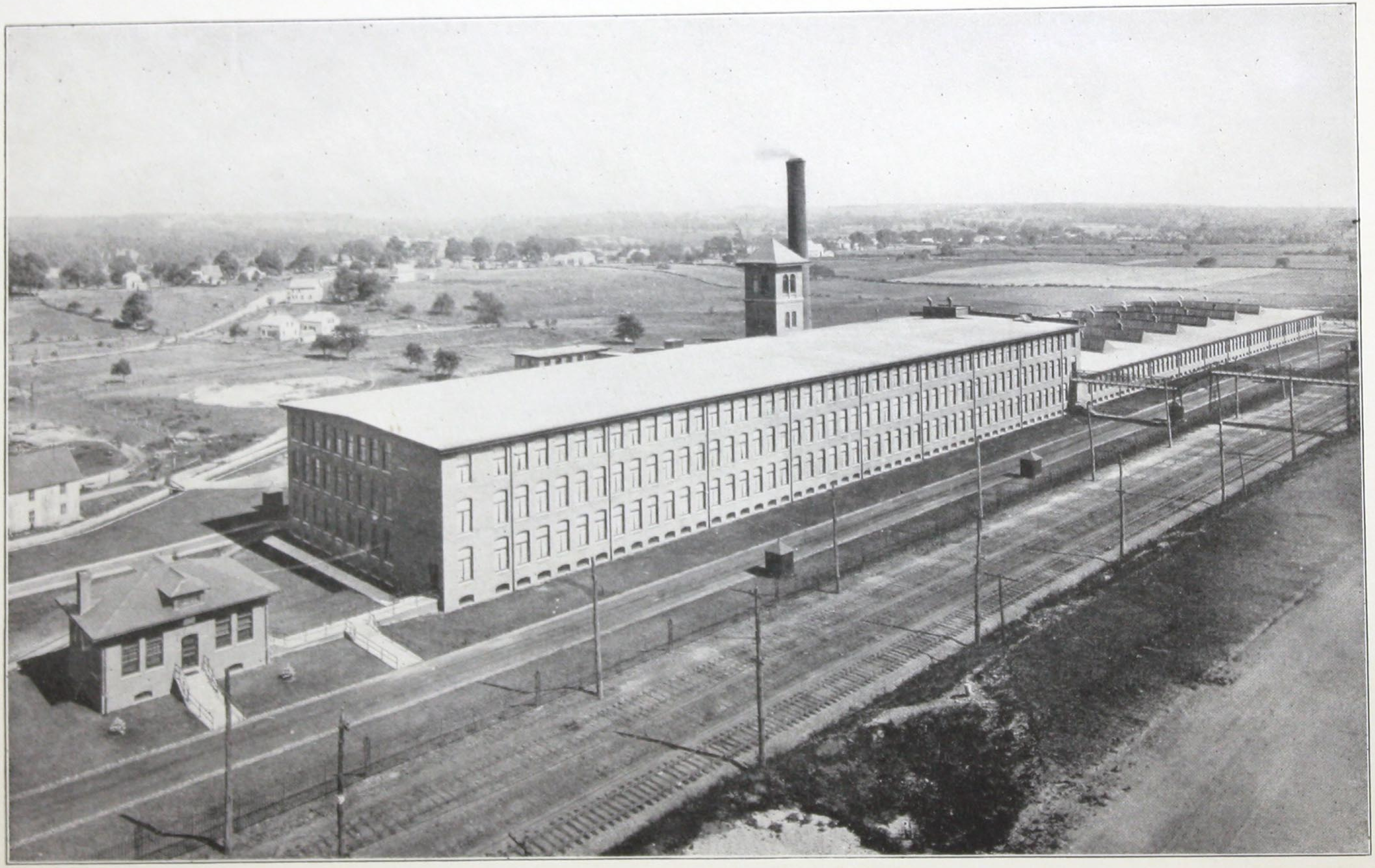
Structural Timber



Heavy Timber Mill Construction Buildings

What Mill Construction Is
Where Mill Construction Should Be Used
How Mill Construction Buildings Should Be Built
Comparative Costs of Industrial Buildings
Mill Construction from an Insurance View-point
Data for Design of Mill Construction Buildings

National Lumber Manufacturers Association
Engineering Bureau
Chicago



A Modern Mill Construction Type of Manufacturing Plant.

(Lockwood, Greene & Co., Engineers, Boston and Chicago.)

Heavy Timber
Mill Construction Buildings

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PUBLISHED BY

ENGINEERING BUREAU

National Lumber Manufacturers Association

CHICAGO

MAY, 1916

GENERAL SERIES No. 25

Contents

Heavy Timber Mill Construction Buildings

By C. E. Paul, Construction Engineer

CHAPTER I.

MILL CONSTRUCTION DEFINED.

The term "mill construction" as commonly used is the name given to that type of building construction in which the interior framing and floors are of timber, arranged in heavy solid masses, and smooth flat surfaces, so as to expose the least number of corners, and to avoid concealed spaces which may not be reached readily in case of fire.

A broader interpretation of the term includes the meaning given above and adds the specification that the building shall be so constructed that fire shall pass as slowly as possible from one part of the structure to another. This means that each floor should be separated from all others by incombustible walls or partitions, and by doors or hatchways which will close automatically in case of fire near them. Stairways, belt passages, and elevator shafts are encased, or preferably located in fireproof towers. Openings in floors for passage of belts, etc., are either avoided or fully protected against passage of fire or water. The proper installation of an approved automatic sprinkler system is of great importance. Ceilings in rooms where highly inflammable stocks are kept or where hazardous processes are followed, should be protected by the use of a fire-retardant material such as plastering laid on wire lath or expanded metal. The ceiling should follow the lines of the timbers without an air space between the two surfaces.

Origin of Type

The "mill construction" type of building originated in the cotton and woolen mills of New England in the early days of that industry. Instances of buildings of the mill construction type are found in the

early part of the nineteenth century, but no great prominence was given to this particular type of structure until the owners of a large number of these mills formed an organization about the year 1835 for the mutual protection of their property from damage by fire. The outgrowth of this primary organization was the formation of the Associated Factory Mutual Fire Insurance Companies.

The results of the combined interests of the factory owners was shown in the recommendation of a standard type of mill building which had proved its value not only through permanence, but also by its fire-resisting qualities. City building ordinances at the present time model their requirements for buildings of the mill construction type largely upon the original suggestions of these mutual insurance companies.

An instance of the durability of timber in properly built mill construction buildings is shown in the Warner mill in Newburyport, Mass. In this building heavy timber girders 45 feet long and spanning three bays have carried their load since the early 50's without signs of failure, and are said to be in as good condition today as when installed. While girders of this length are not common at the present time and shorter lengths are used for the same purpose, this instance shows the dependence which may be put in mill construction when properly selected timber of a high quality is used.

What Mill Construction Means Today

The marked success of early heavy timber structures of the mill construction type led to the popular use of this form of construction in practically all kinds of large buildings. As its use developed, new problems arose which made necessary a departure from the original designs. This variation to suit the case in hand finally resulted in three general classes of framing, each commonly referred to by builders as mill construction. These classes have certain basic points in common, such as heavy timber, brick, stone, or concrete walls; stairways and elevators enclosed in fireproof shafts or towers; floors with no openings or with all openings protected by fireproof covers; each floor or room isolated by means of automatic fireproof doors or fire walls; windows protected by shutters or by the use of wire glass; sprinkler equipment, etc.

These three general types of framing may be classed as follows:

1. Floors of heavy plank laid flat upon large girders which are spaced from 8 to 11 feet on centers. These girders are supported by wood posts or columns spaced from 16 to 25 feet apart. This type is often referred to as "Standard Mill Construction."

2. Floors of heavy plank laid on edge and supported by girders which are spaced from 12 to 18 feet on centers. These girders are supported by wood posts or columns spaced 16 feet or over apart, depending upon the design of the structure. This type is called "Mill Construction with Laminated Floors."

3. Floors of heavy plank laid flat upon large beams which are spaced from 4 to 10 feet on centers and supported by girders spaced as far apart as the loading will allow. These girders are carried by wood posts or columns located as far apart as consistent with the general design of the building. A spacing of from 20 to 25 feet is not uncommon for columns in this class of framing where the loading is not excessive. This type is more generally known as "Semi-Mill Construction."

Each of these types is provided with a lighter top-floor to take the wear and give a finished surface. Construction details will be given in the chapters which follow.

What Mill Construction Is Not

In order that all sides of the question may be presented, the following abstracts from Report No. V, issued by the Insurance Engineering Experiment Station under direction of the Boston Manufacturers Mutual Fire Insurance Co., may aid in eliminating erroneous ideas.

"Mill-construction does not consist in disposing a given quantity of materials so that the whole interior of a building becomes a series of wooden cells; being pervaded with concealed spaces, either directly connected each with the other or by cracks through which fire may freely pass where it cannot be reached by water.

"It does not consist in an open-timber construction of floors and roof resembling mill-construction, but of light and insufficient size in timber, and thin planks, without fire-stops or fire-guards from floor to floor.

"It does not consist in connecting floor with floor by combustible wooden stairways encased in wood less than two inches thick.

"It does not consist in putting in very numerous divisions or partitions of light wood."

"It does not consist in permitting the use of varnish upon woodwork over which a fire will pass rapidly.

"It does not consist in leaving windows exposed to adjacent buildings unguarded by fire-shutters or wired glass.

"It is dangerous to paint, varnish, fill or encase heavy timbers and thick plank as they are customarily delivered, lest what is called dry-rot should be caused for lack of ventilation or opportunity to season.

"It does not consist in leaving even the best-constructed building in which dangerous occupations are followed without automatic sprinklers, and without a complete and adequate equipment of pumps, pipes, and hydrants."

"It follows that if plastering is to be put upon a ceiling following the line of the underside of the floor and the timber, it should be plain lime-mortar plastering, which is sufficiently porous to permit seasoning. The addition of the skim-coat of lime-putty is hazardous, especially if the top-floor is laid upon resin-sized or asphalt paper. This rule applies to almost all timber as now delivered.

"All the faults above recited have been committed in buildings purporting to be of mill construction, and all form a part of the common practice in 'combustible architecture.' "

Mill Construction and Slow-Burning Construction

The terms "mill construction" and "slow-burning construction" are used in most instances without a true clearness of meaning. It is true that mill construction, is one of the best types of slow-burning construction, but there are other types of structures which are referred to under this same classification. The popular distinction is best shown in the building ordinances of various cities. In mill construction, only timbers of large size are used, but in slow-burning construction small timbers protected by metal lath and plaster or other fire resisting materials are frequently installed. Instead of the thick floors required in mill construction, lighter material is used with a fire retardant layer between the under floor and the wearing surface. Plaster covered steel or iron members may also form the main part of the framing in this latter type of building. The following abstracts from the 1915 Revised Building Ordinance of the City of Chicago will illustrate this distinction.

"*Slow-Burning Construction Defined.* The term "Slow-Burning Construction" shall apply to all buildings in which the structural members, other than walls elsewhere required to be of masonry which carry the loads and strains which come upon the floor and roofs thereof are made wholly or in part of combustible material, but throughout which the structural metallic members, if used, shall be protected against injury from fire by coverings of fireproof material. Underside of joists shall be protected by a covering of three coats of plaster laid on metal lath; and a layer of mortar or other

incombustible material at least one and one-half inches thick shall be applied on all floor and roof surfaces above the joists of the same. Wood posts, if used, shall be of not less than one hundred square inches sectional area. Wood girders, if used, shall be of not less than seventy-two square inches sectional area."

"*Definition—Mill Construction Requirements.* The term "Mill Construction" shall apply to all buildings in which wooden posts, if used, have a sectional area of not less than one hundred square inches, and wooden girders and joists a sectional area of not less than seventy-two square inches, and roofs, if of wood, a thickness of not less than two and five-eighths inches in a single layer, and floors, if of wood, a thickness of not less than three and one-half inches in not more than two layers, the lower one of which shall be not less than two and five-eighths inches in thickness, and in which all structural metallic members, if used, are fireproofed as required for fireproof construction, and in which all floors and roofs not constructed as above are of fireproof construction as elsewhere required for fireproof construction in this ordinance."

Mill Construction Used to Advantage

Mill construction has always been looked upon with favor for buildings in which ordinary manufacturing industries are carried on. Warehouses and buildings for storage of merchandise, stores, office buildings, factories, shops, and all buildings of moderate height which are not to be used for extremely hazardous purposes from a fire protection standpoint, are later developments of this type of construction. City building codes limit the height of building and size of open spaces in buildings. They also specify the minimum sizes of timber which shall be used, and other similar details.

The following extract from the report of G. B. Hegart, Engineer, The Commission of Public Docks, Portland, Oregon, for the year ending November 30, 1915, indicates a few of the special advantages of mill construction:

"The adoption of heavy mill or slow-burning construction in preference to fireproof construction, was done both on account of the saving in the initial cost and the necessity of taking into consideration the useful or commercial life of structures of this character, as it is not at the present time possible to foresee the type of waterfront structures that will be demanded to meet changed requirements twenty-five or thirty years hence, when extensive alterations may have to be made to present structures, which can be more readily accomplished in timber than in fireproof construction, or an entire new design may be found necessary to meet the changes in requirements."

Mill Construction and the Architect

This bulletin is intended to supplement as an educational treatise, and to aid technically, the work of the architect or engineer who may not have the time or opportunity to compile such information for himself. While heavy timber mill construction buildings are easy to build and have the results of long experience to guide the builder, the services of a competent architect or engineer are always advisable. In no class of buildings can safety and economy of design be more positively assured.

CHAPTER II.

EXTERIOR WALLS, FIRE WALLS, AND ENCLOSURES.

Foundations The stability of any building depends to a great extent upon the nature of the foundations and the bearing power of the soil upon which these foundations rest. Not only must the walls have footings of sufficient size, but all piers which support columns or isolated loads must also be provided with ample bearing surface. Heavy machines or equipment may be supported upon foundations which are separate from the main foundations of the building. This is advisable in all cases where heavy shocks or vibrations are likely to occur.

The footings and foundation walls of modern mill buildings are of plain or reinforced concrete. A lean mixture of one part Portland cement, three parts clean sand, and five parts of broken stone or screened gravel, should be suitable for footings in ordinary cases, while a 1:2:4: mixture will make strong, watertight foundation walls if the materials are carefully graded and properly handled. It is essential that the concrete be extremely well mixed.

Safe bearing values for different kinds of soil are as given in Table I:

Table I.—Bearing Power of Soils.

Rock	10 to 200 tons per sq. ft.
Gravel, compacted	8 to 10 " " " "
Sand, clean and compact	4 to 6 " " " "
Clay on thick beds, always dry	4 to 6 " " " "
Clay on thick beds, moderately dry	2 to 4 " " " "
Sand, clean and dry	2 to 4 " " " "
Dry earth	1 to 2 " " " "
Quicksand and wet soil	½ to 1 " " " "

The unit bearing on footings should be proportioned in such a manner as to allow equal settlement under all parts of a structure. In general, footings for natural foundations should be made 1 foot 6 inches, or 2 feet thick. If pile foundations are used, the footings should be made 3 feet thick with

the pile head extending 1 foot into the concrete. Foundation piles should not be spaced closer than 2 feet on centers in any direction, and at least 2 feet 6 inches should be allowed in one direction. Wood piling should always be cut off below water level.

Wherever exposed to the action of frost, footings should lie from 4 feet to 6 feet below grade, depending upon the climatic location. In any case footings should be carried to the firmest bearing strata within reasonable reach.

The thickness of the foundation walls or the size of the isolated piers will depend upon the load to be carried. This load is determined approximately from preliminary plans of the building, and from the weight of machinery, equipment, or materials which is to be carried on the floors of the structure. In calculating the live load, allowance must be made for the effect of impact from machines and equipment together with the overturning effect on the leeward side due to the wind.

If the soil is wet and a dry interior is to be assured, the basement walls and floor should be waterproofed during construction. This waterproofing may consist of a continuous layer of bituminous material placed on the outer surface of the walls, extending through the walls at the footings, and forming a tight membrane under the wearing coat of the basement floor, or by the use of a rich, properly graded mixture of Portland cement concrete containing a reliable integral waterproofing compound.

Exterior Walls

Exterior walls may be made of heavy timber construction as in the case of floors, if the structure is to be built outside of conflagration districts and well separated from other buildings. The posts which are to form the exterior framing should be of a size needed to carry the load from the floor above, but should not be less than 10 inches by 10 inches. These posts should be spaced from 8 to 10 feet apart as in the case of the floor girders, and should be thoroughly braced at the corners of the building and around openings to provide stiffness.

The walls may be of plank 2 inches or more in thickness. Tongued and grooved or splined material is placed vertically and nailed to horizontal girths extending between the posts. Square-edged plank may be used by covering the cracks with

½-inch battens. If metal siding or slate is to be used as an exterior finish, the planks should be placed horizontally and fastened to the posts and intermediate studs if needed. Planks nailed diagonally will aid in stiffening the building, but there is a small waste of material involved. All interior surfaces should be left exposed so that water may reach them easily in case of fire.

If a wall of incombustible material is required by the local building ordinance, or if it is desired to construct the building in such a manner as to meet the recommendations of insurance underwriters, brick, or reinforced concrete should be used.

The pilastered form of brick or reinforced concrete wall gives large window areas and furnishes support to the main girders of the floors where needed, but may lack the rigidity of a solid wall. This general type of construction may be carried out either in the form of curtain walls or panel walls at the choice of the designer. In the absence of a local building ordinance which determines the proper thicknesses to be used in the different parts of brick or concrete exterior walls, it is suggested that the sizes given in the Building Code Recommended by the National Board of Fire Underwriters be followed.

Fire and Party Walls Fire walls and party walls should be built of brick or reinforced concrete and should extend 3 feet above roof. The thickness and general design is regulated by the local ordinance, or may be governed by the recommendations of the National Board of Fire Underwriters. For the sake of economy designers should take care to keep the floor areas of the maximum proportions at which fire walls are not required, as the cost of fire walls and the protection of openings in walls, add materially to the cost of a structure. Maximum floor areas between fire walls or exterior walls of mill construction buildings not over 65 feet high as recommended by the National Board of Fire Underwriters are as follows:

	Without Sprinklers	With Sprinklers
Building fronting on one street	6,500 sq. ft.	13,000 sq. ft.
Building fronting on two streets	8,000 sq. ft.	16,000 sq. ft.
Building fronting on three or more streets	10,000 sq. ft.	20,000 sq. ft.

Local building ordinances may vary from these areas and should be consulted in any case.

Enclosure Walls Walls which serve as enclosures for stairways, elevators, etc., should be self sustaining and of incombustible material. Brick walls not less than 12 inches thick, or reinforced concrete not less than 8 inches thick are commonly used for this purpose. In special cases where the wall is less than 8 feet on a side and has no openings, a brick wall 8 inches thick may be used if it does not extend more than one story in height.

The walls of stairways and elevator enclosures when inside of a building should extend through all floors and rise about 3 feet above the roof. No interior windows should be allowed, and all openings from the different floors should be protected by automatic fire doors. All stairway doors should be self-closing.

Belts or power drives should be located in a special tower or shaft constructed of incombustible material as in the case of stairways and elevators. Openings to such shafts should be self-closing.

CHAPTER III.

FLOORS.

General Construction One of the distinctive purposes of mill construction is to obtain strength and stiffness with a minimum amount of timber surface and corners exposed to attack by fire. Large supporting members and flat, smooth, heavy floors provide this requirement. Large timbers do not ignite readily, and if exposed to fire burn slowly and with but slight penetration after a considerable period of time. Flat, smooth surfaces possess this same resistance to combustion, and may be reached easily by water from sprinklers or hose. While three general types of construction were described briefly in Chapter I, each type is based upon these fundamental principles and varies only according to the needs of design in a given case.

Heavy timber posts support large timber girders spaced as far apart as the design will allow. These girders support a thick main or carrying floor direct without aid of joists or smaller timbers, except in semi-mill construction. The main floor is covered with two or more layers of waterproof paper, or similar material, to prevent leakage of water or passage of dirt from the floor above. A lighter hardwood top or wearing floor is laid on the paper and completes the total thickness of floor.

The factor of safety used in calculations for size of girders and columns is sufficient to allow serious charring by fire and still leave strength to support the floor loads. Wood posts have successfully withstood fire that would have entirely crippled unprotected cast iron or steel columns.

Beams of sufficient strength to carry the imposed loads may deflect or vibrate under the action of machinery or impact; therefore, the factors of weight, deflection, vibration and impact should be considered in finding the dimensions of beams that may be used in a given case.

Size of Bays The width of floor and roof bays will vary from 8 to 11 feet on centers where the planks of the main floor are laid flat and no intermediate beams used. If the planks are set on edge, the bays will commonly vary from 12 to 18 feet in width, depending in any case upon the general design of the building, the amount of floor load, and an economical arrangement of the pipes for the sprinkler system. Economy in the use of lumber is effected by making the span such that the full working strength of a given commercial size of material may be utilized, and the material used in standard lengths. Excessive deflections must be guarded against in any design.

The length of bays may be as great as 20 to 25 feet, but 16 feet is more common in ordinary buildings. Again, the design of the building and the sizes of material easily obtained determine this dimension.

Crosby and Fiske in their "Hand Book of Fire Protection" refer to the width of bays as follows:

"Narrow bay construction (4 feet to 5 feet center to center of timbers) is not true mill construction and is undesirable for several reasons. There are more corners, angles and surfaces on which fire may feed and spread. Water from sprinklers or hose streams cannot be used as advantageously. Owing to the expense, and also because of the greater number of sprinklers in the same fire area, it is not always feasible to place a line of sprinklers in every bay, and if this latter is not done the sprinkler protection is not as satisfactory. Less than 6 foot bays are not advised, and if used the building should not be classed as of 'mill' construction."

Height of Stories The height of different stories of a building may be controlled by the character of occupancy or by special processes necessary in the manufacturing industries. Where no special features are to be provided for, the heights shown in Table II may be used as a guide:

Table II.—Height of Stories from Floor to Floor.

Width of Building	Height of Stories
25 feet	12 feet
50 feet	13 feet
75 feet	14 feet
100 feet	15 feet
125 feet	15 feet

The National Board of Fire Underwriters recommend that no story of any building above the first story shall exceed 15 feet in height.

Minimum Sizes of Material Building ordinances and insurance codes or specifications have established certain minimum sizes of girders and thickness of floor plank. This action tends to preserve the distinctive points of mill construction, and separate it from ordinary light framing. While all ordinances and codes do not agree in detail, the same purpose is indicated in each.

Girders or beams are commonly required to be at least 6 inches in either dimension, and often a cross-section area of 72 square inches is demanded. Some cities require 8 inches as a minimum dimension. All timbers are to be planed on all sides.

The main or carrying floor should be at least 3 inches thick with tongued and grooved or splined joints if laid flat upon the girders. For plank 4 inches or more in thickness, the edges should be grooved to take a 3/4-inch by 1 1/2-inch hardwood spline. The top hardwood floor may be of a 1-inch material. All material should be surfaced on all sides. The sizes given above are nominal and not actual.

Girders Although a minimum dimension of 6 inches (nominal) is specified by building ordinances and insurance recommendations, girders of greater depth than width are commonly used. Formulas for finding the size of girder to carry a given floor load will be found in a special section at the end of this bulletin.

Girders are preferably of single stick, but for sizes above 14 inches by 16 inches it is often advantageous to use two pieces 8 inches by 16 inches, or a similar combination, bolted together securely side by side with the larger dimension vertical. It has been the custom to leave an air space about 3/4-inch wide between the two members thus fastened, but modern practice favors placing the two girders close together without air space. It is claimed that the space between double members allows the entrance of fire into a place which is difficult to reach with the ordinary sprinkler system or even with a stream from a hose.

Bolts 3/4-inch diameter fitted with nuts and 3-inch washers are often used to fasten double girders. The extreme bolts are placed about 2 feet in from the ends, while the others are stag-

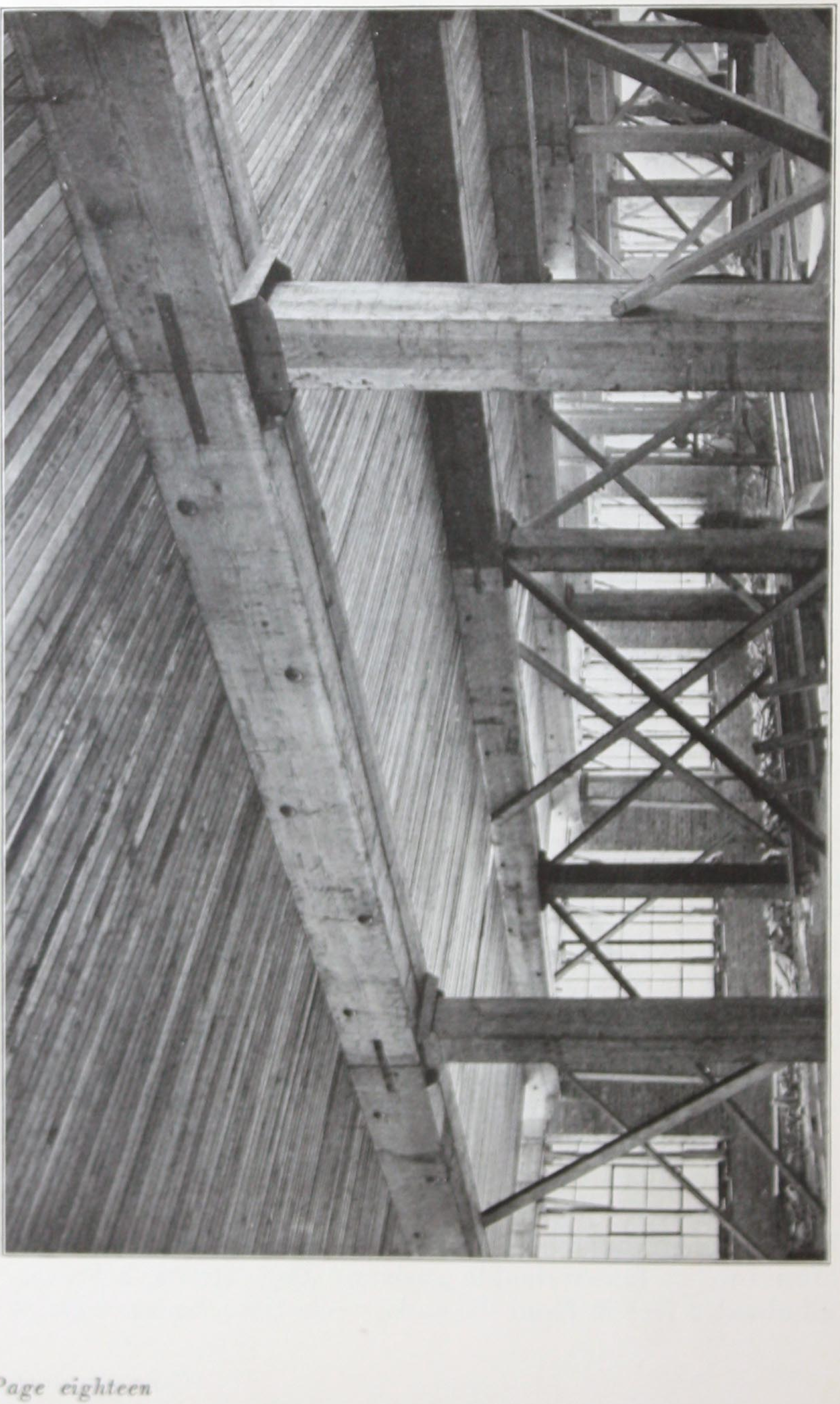

Fig. 1. Heavy Timber Framing with Laminated Floor.

gered at equal spacing along the length. The spacing longitudinally should not be greater than four times the depth of the girder.

Where girders meet at the columns, they should be fitted around the column or butted up close to it. The ends of girders may be held in place by steel or iron straps spiked, bolted, or held in place by lag screws, as shown in Fig. 1. If the style of post cap will allow, the sides of the post cap which project upward may be used as straps for the girders.

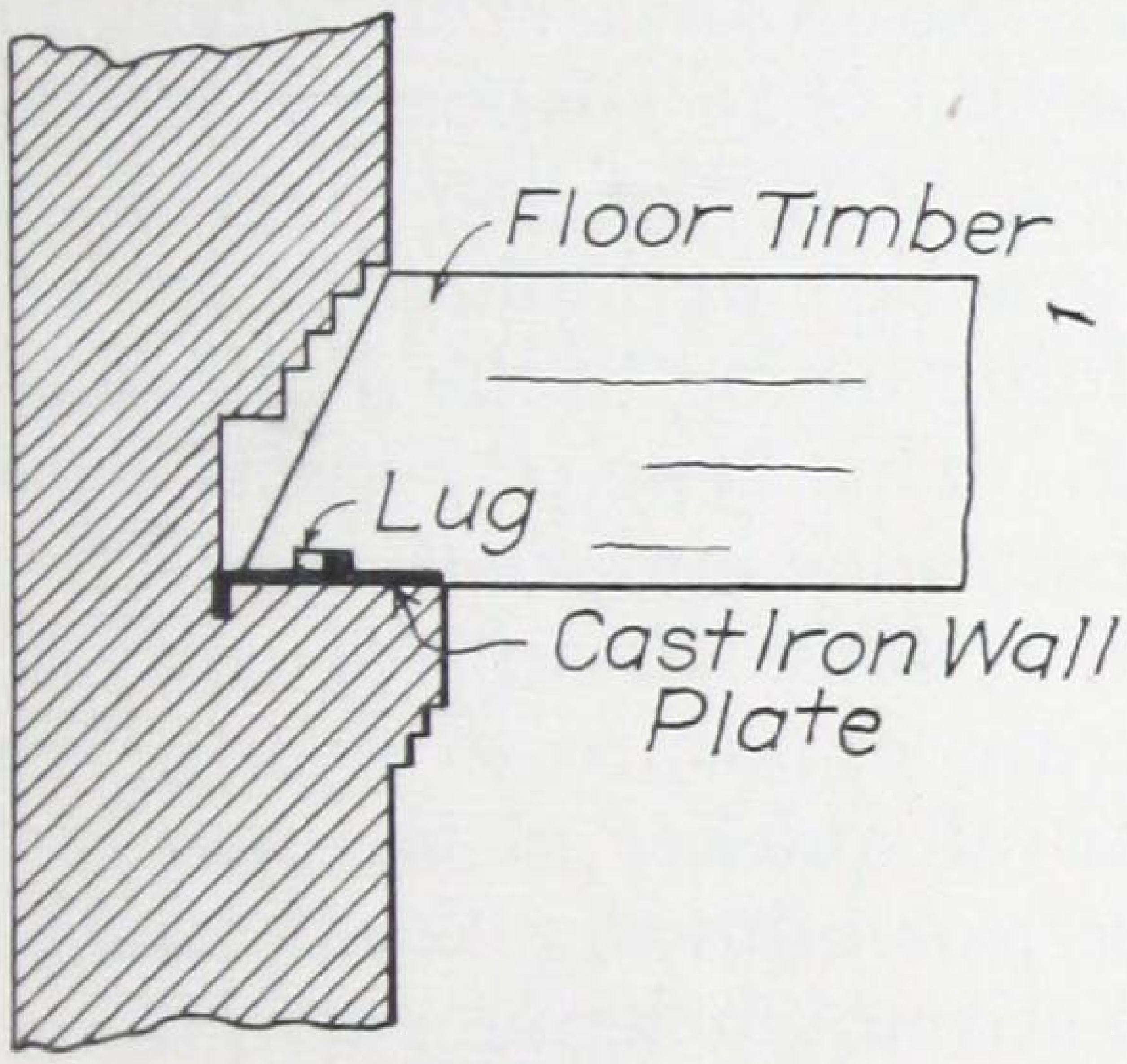

Fig. 2. Method of Supporting Girder on Wall Plate.

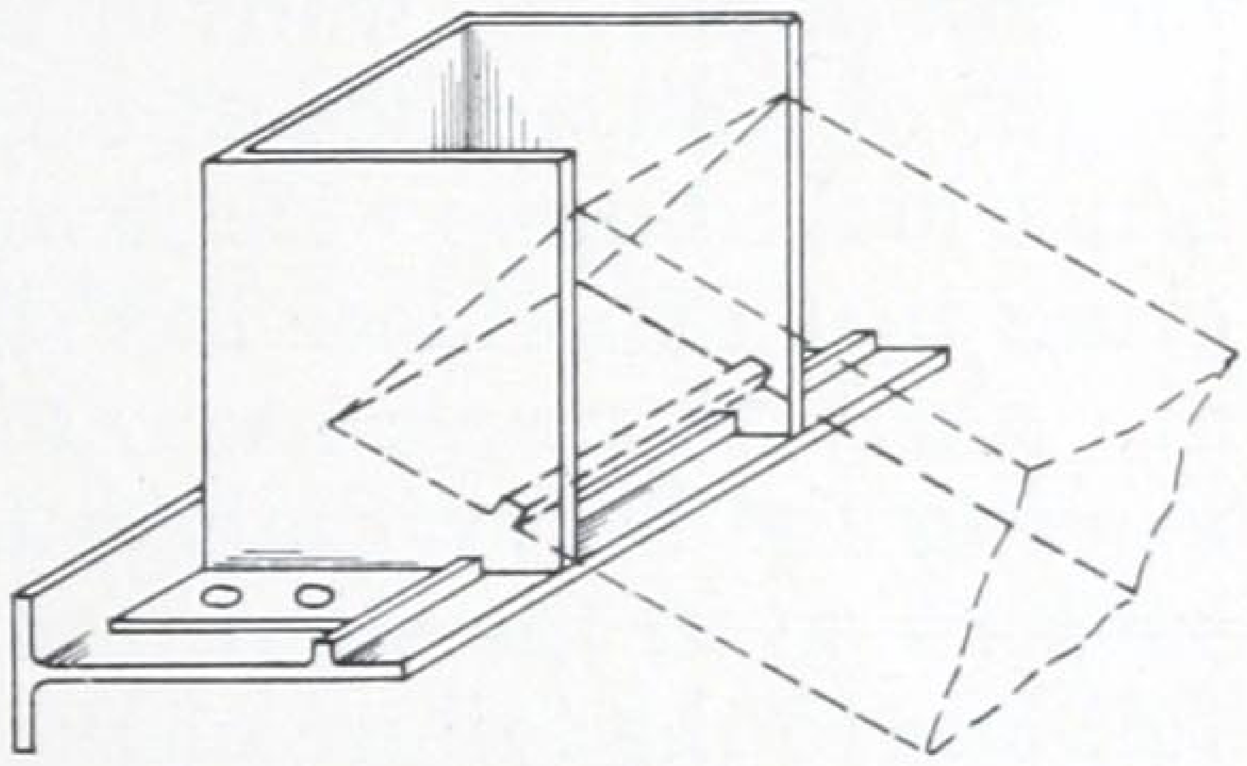

Fig. 3. Wall Box for Holding End of Girder in Wall.

The length of the bearing at the ends of girders should be such that the bearing area will be sufficient to allow a suitable unit stress in compression across the grain of the wood. A minimum length of 5 inches is often required, but an exact determination should be made after the width of girder is known. Methods of calculation and values of unit stresses for compressive strength of timber will be found in a section at the end of this bulletin. If the local building ordinance specifies definite values, they should be used in all calculations.

Girders are supported at the wall by metal wall plates or wall boxes built into the wall as shown in Fig. 2 and Fig. 3, thus distributing the loads more evenly on the brickwork. Wall plates should have two flanges—one to anchor the plate to the wall, and the other to hold the girder on the plate. Care should be taken to see that a ½-inch air space is left around the ends of girders for ventilation, so as to prevent the appearance of dry rot. It is advisable to allow end play in girders to prevent strains in the walls. Ends of girders should be cut at an angle

such that in case of damage by fire, the member may tip out of the wall opening without disturbing the wall. At columns, girders are supported by steel or iron caps.

Use of Intermediate Beams Where intermediate beams are used to support a floor in semi-mill construction, it is preferable that the beams should rest on the top of the girders direct. The width of the main girder is usually sufficient to give ample bearing for the ends of the beams in the bays on each side of the girder, even when the ends butt together. Common practice is to suspend intermediate beams between the main girders by the use of steel or iron stirrups or hangers. This practice undoubtedly lowers the cost of the side walls of the building owing to the diminished height of wall needed at each floor. This type of construction is not looked upon with favor by insurance underwriters. They claim that experience has shown that such stirrups or hangers are likely to prove hazardous during exposure to fire, either causing the heavy timbers to burn off quicker at the point of suspension in the stirrup or hanger, or allowing the beams to fall due to the failure of the metal stirrup or hanger itself.

The Crosby-Fiske Hand Book of Fire Protection contains the following comment upon this point:

> "Mill construction, particularly in the Middle West, has suffered unfairly in reputation by reason of disastrous fire results, because buildings somewhat resembling this type have borne its name. They may have had floors and roofs of plank on wide spaced timbers, but in other particulars violated the principles of 'mill construction.' A common defect has been the use of exposed steel or iron stirrups to hold important floor timbers."

Floors Floors may be of dressed and matched or splined plank 3 inches (nominal) or more in thickness nailed direct to the girders. This type of floor is often called a "mill floor." If heavy loads are to be carried on long spans, planks 6 inches or 8 inches wide are set on edge close together, firmly nailed at each end and at about 18-inch intervals with 60 D. nails, alternating top and bottom, thus forming a "laminated floor." Each of these floors is covered with two or more thicknesses of waterproof paper or similar material and then by a top, or wearing floor laid at right angles to the direction of the underfloor. Material is surfaced on all sides and edges of plank beveled to serve as a finish on the ceiling below.

Where plank floors are laid flat, the boards should be two bays in length if possible and laid to break joints every 4 feet. With laminated floors, it may be difficult to obtain plank two bays in length. In such a case, the planks may be laid with the ends extending between centers of girders with one plank

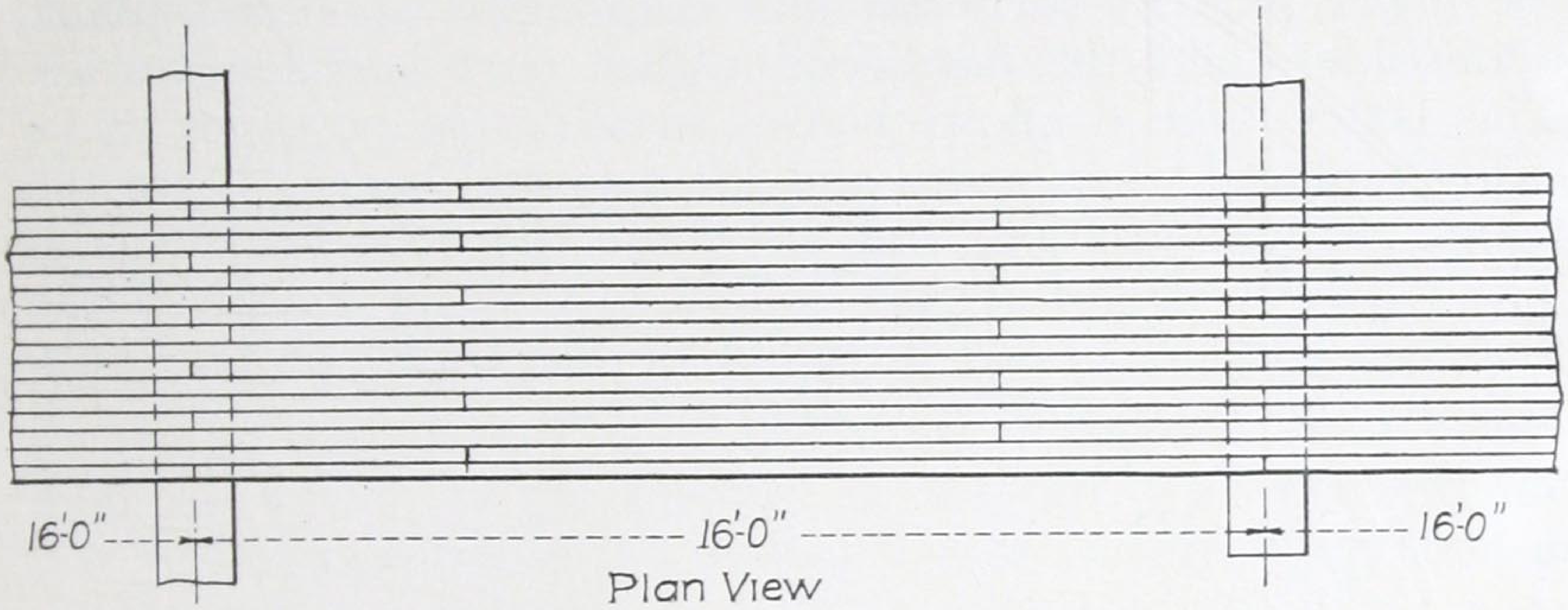

Fig. 4. Laminated Floor with Joints at Quarter Points.

laid across the girder at frequent intervals (every sixth or eighth piece) to act as a tie in the floor. Or, by another method, the ends of planks should join at or near the quarter point of the span between girders, taking care to break joints in such a way that no continuous line across the floor will occur. Fig. 4 shows an instance of this kind in which the span between girders is 16 feet and the planks are 16 feet long. The method of lamination shown in Fig. 4 is as follows:

Every fourth piece of plank extends from center of girder to center of next girder. Next to this piece of plank, a second piece of the same length is nailed with the end spaced at a quarter point of the span between girders, thus allowing one end of the length to project three-fourths of the way across one span and one-fourth way across the other. The next piece of plank is placed over the opposite girder in the same manner that the previous is placed over the first girder. The lamination is completed by placing a length of plank from center of girder to center of girder as in the first case. Care is taken to see that each plank is nailed firmly in place with a tight joint between each piece of the floor.

In laying laminated floors, it is advisable to omit the last two planks at walls until after glazing and roofing have been completed. Then these spaces should be filled in close against the walls. It is often recommended that laminated floors be laid without nailing to the girders which support the floor, so that expansion in the floors due to dampness will not cause movement in the girders at the walls.

The top-floor may be of softwood or hardwood as use demands. Tongued and grooved flooring is used almost entirely. Square-edged flooring is easier to replace when repairs are needed, but wears less around nails, thus making an uneven floor. Some of the best buildings have a double top-floor, the lower part of softwood laid diagonally upon the plank under-floor, and the hardwood upper part laid lengthwise. This latter method allows boards in alleys or passages to be easily replaced when worn, and the diagonal boards brace the floors, reduce vibration, and distribute the floor load evenly. The top-floor should always be laid so that the length of the pieces is parallel to the direction of the traffic or trucking. Usually this is lengthwise of the building.

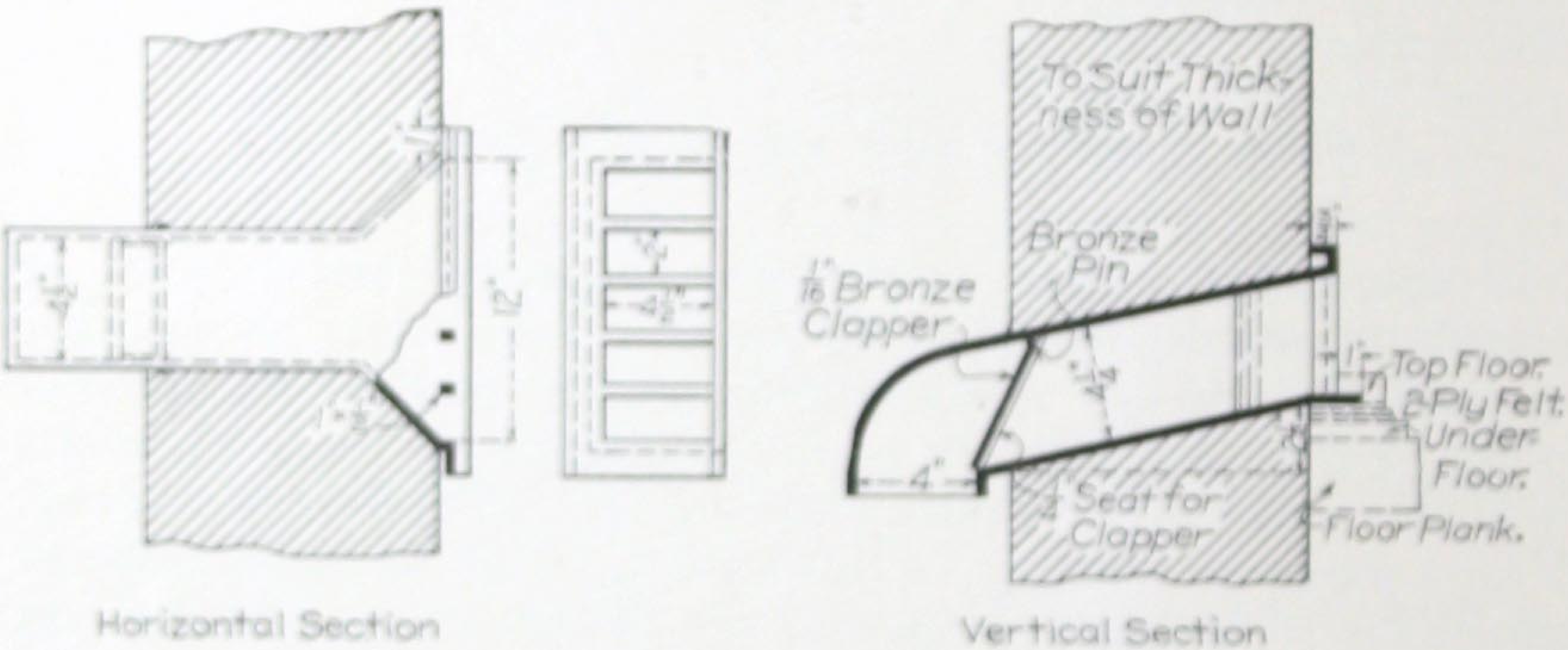

Fig. 5. Scupper for Drainage of Floors.

If extra precaution is desired to prevent leakage of water through floors, the various layers of waterproof paper should be laid to break joints and each joint mopped with hot tar or a similar protective material. Also, floors may be given a pitch of 1 inch in 20 feet, and scuppers similar to that shown in Fig. 5 installed at floor level. These are ordinarily spaced from 20 to 40 feet apart along the wall.

The Associated Factory Mutual Fire Insurance Companies recommend the use of an approved elastic felt instead of waterproof paper. Their experience has been that felt properly laid gives better satisfaction in the long run. These companies recommend that a rough board floor be laid on top of the heavy plank floor, and that the waterproof felt be placed on this rough floor. A fairly smooth surface must be provided

before the felt is laid, and any irregularity in the floor more than 1/8 inch deep should be filled up. Two layers of felt are used, breaking joints, and mopped with a sealing compound between the plies and on top of the felt. These companies recommend that the felt be turned up 6 inches at the posts and at the side walls. The hardwood top-floor is laid in the hot compound closely following the final mopping, so that the nails holding it down are tightly gripped.

At the walls the felt is protected by a counterflashing of galvanized iron, or by a base-board nailed in place with the joint between it and the floor covered by a quarter-round. Both the base-board and quarter-round should be kept free from the top-floor to allow the latter to move without breaking the corner of the turn-up in the felt. At the columns the felt may be protected by base-board and quarter-round as at the walls.

Fig. 6 gives details of floor construction and flashing at side walls, as described above, and as recommended by the Associated Factory Mutual Fire Insurance Companies.

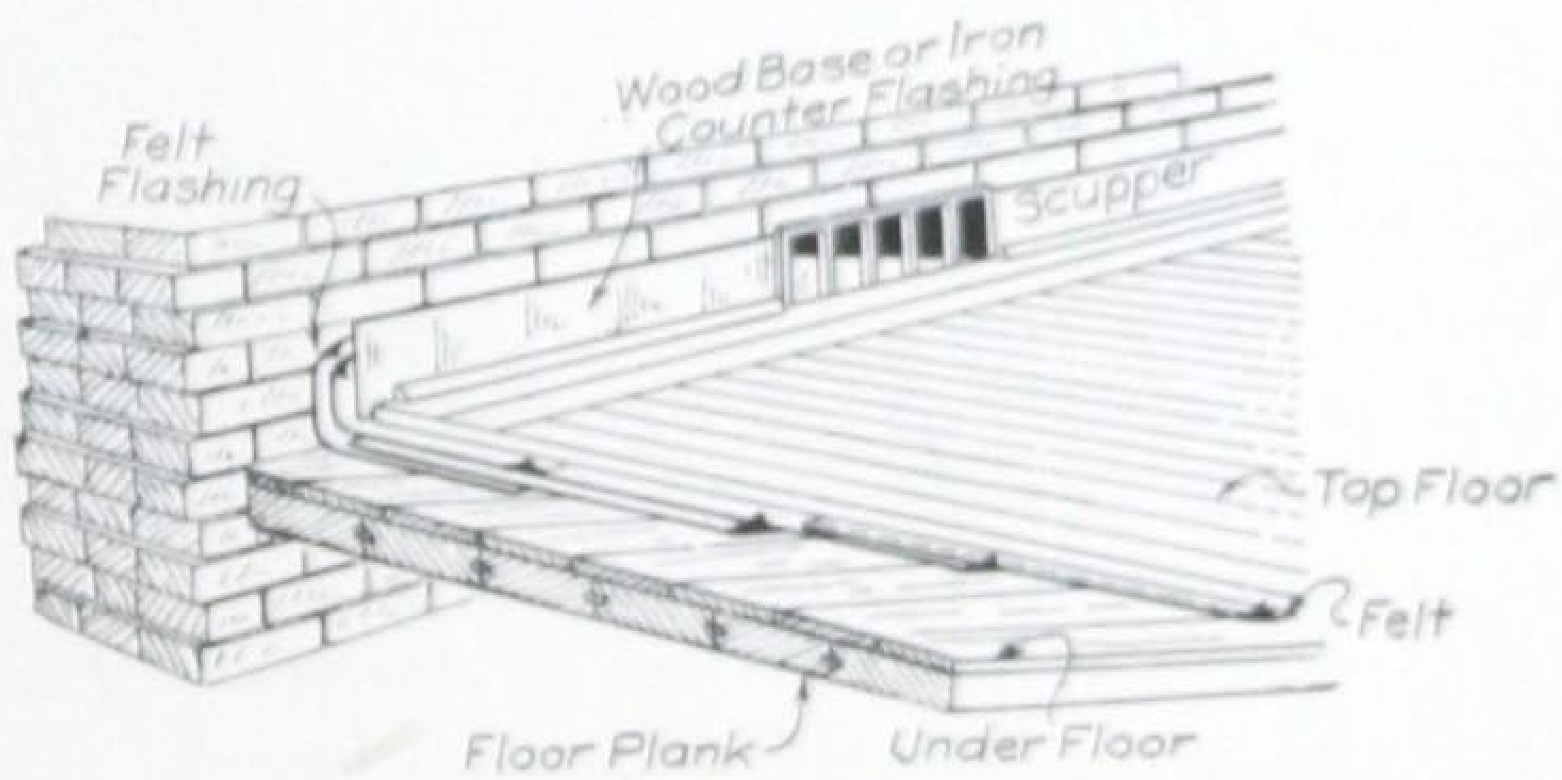

Fig. 6. Details of Floor Construction.

The following extracts from the Building Code Recommended by the National Board of Fire Underwriters are of interest in connection with the general design of floor timbers and floors:

"Wooden girders or floor timbers shall be suitable for the load carried, but in no case less than 6 in. either dimension, and shall rest on iron plates on wall ledges and where entering walls shall be self-releasing. Walls may be corbeled out to support floor timbers where necessary. The corbeling shall not exceed 2 in.

"So far as possible, girders or floor timbers shall be single stick.

"Where wooden beams enter walls on opposite sides, there shall be at least 12 in. of masonry between ends of beams, and in no case shall they enter more than one-quarter the thickness of the wall.

"Width of floor bays shall be between 6 and 11 ft.

"The practice in mill-construction of supporting the ends of beams on girders by means of metal stirrups or bracket hangers is objectionable. Experience has shown that such metal supports are likely to lose their strength when attacked by fire and so cause collapse.

"Floors shall be not less than 3 inches ($2\frac{3}{4}$ inches dressed) flooring laid crossways or diagonally. Top flooring shall not extend closer than $\frac{1}{2}$ inch to walls so as to allow for swelling in case floor becomes wet. This space shall be covered by a moulding so arranged that it will not obstruct movement of the flooring.

"Waterproofing shall be laid between the planking and the floor in such manner as to make a thoroughly waterproof floor to a height of at least 3 inches above floor level. When there are no scuppers, the elevator or stairwells may be used as drains for the floors, in which case the waterproofing material need not be flashed up at these points.

"All exposed woodwork in exterior construction shall be planed smooth.

"Pipes or conduits extending through floors shall be fitted with metal thimbles and made watertight to a distance of 3 inches above floor.

"All floors shall be arranged to drain to elevator well or some other point where minimum damage will result from water. It is recommended that, where feasible, floors be built with a slight pitch (about 1 inch to 20 feet) and have proper scuppers or drain pipes.

*"Two thicknesses of waterproofing paper or its equivalent to be laid between the planking and the flooring in such a manner as to make a thoroughly waterproof floor to a height of at least 3 inches above floor level. If the paper itself is waterproof, the joints should be swabbed with tar, pitch, or their equivalent and overlapped at least 2 inches. If the paper is not waterproof, the entire surface of the lower layer to be swabbed with tar, pitch, or their equivalent and the upper layer placed on the lower while hot. Waterproofing paper to be flashed up at least 3 inches above floor openings and protected with mop board."

Fig. 7 shows an interesting point in connection with the erection of the framing in a mill construction building where laminated floors are used. This building was put up during cold weather, and the temperature was considered to be too low for laying brickwork properly. In order not to hinder the progress of the structure, it was decided to go ahead with the framing of the floors and follow later with the walls. Supports similar to those shown at the end of the girder in Fig. 7 were used throughout each story of the building above the brickwork already placed. The posts were supported in place by braces at the cap to prevent them from falling sideways, and in the opposite direction by the girders themselves. The ends of the flooring at the walls were supported by a temporary plate which could be easily removed after the final wall support was in place.

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*Uniform Requirements.

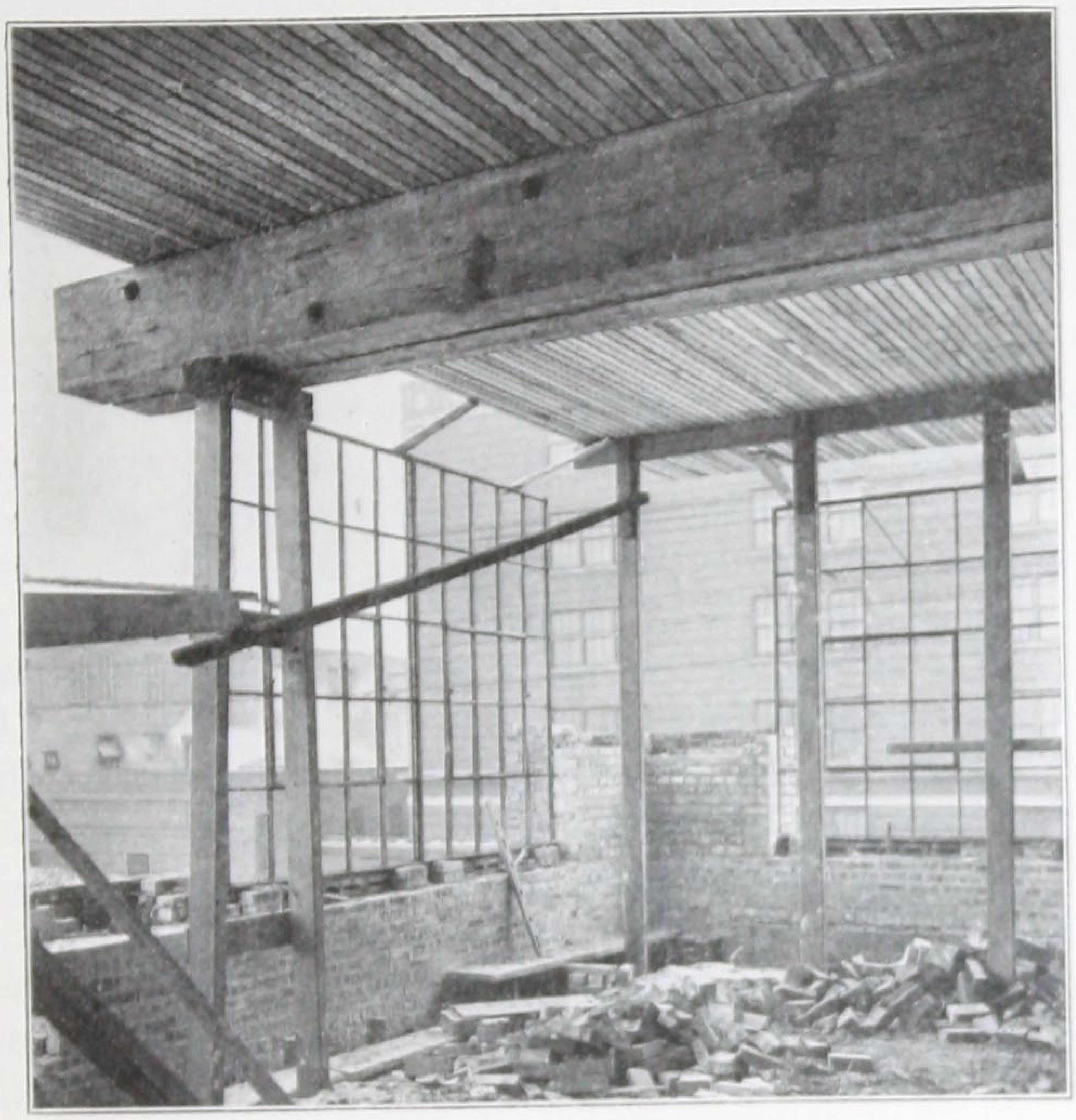

Fig. 7. Framing and Floors in Place in Advance of Walls.

Basement Floors Creosoted wood block floors for basements or for shop floors give excellent service and are easy for workmen to stand on. A floor of this type made of blocks well seasoned before treatment and laying, having the joints made with an approved cement or pitch filler, should last twenty years or more. Seasoning prevents shrinkage in the blocks after laying where used indoors. This is the opposite condition to that met in outdoor work. In the creosoting, an empty cell treating process, with five to eight pounds of oil per cubic foot, gives an excellent floor at moderate cost. When not subject to moisture or water soaking, etc., the blocks can be laid with close joints. Under moist conditions, a 1/8-inch joint closed with pitch is advisable. A good specification for a wood block floor is as follows:

In wet ground, first spread a thoroughly compact layer of cinders or gravel about 6 to 12 inches deep as the sub-foundation. Then place a 4-inch layer of Portland cement

concrete. A ½-inch layer of sand and cement grout is spread on top of the concrete and smoothed preferably with a template until level to serve as a bed or cushion for the blocks.

Wood blocks may be used for upper floors if desired by placing under them two layers of paper laid in pitch, bedding the blocks in hot pitch and filling the joints with the same material.

A good basement or shop floor is made by laying a wood wearing surface on a base consisting of concrete and tar or asphalt. Such a floor is made by first spreading a 4-inch layer of screened gravel or stone not larger than 2½ inches mixed with tar. The tar is heated to 200° F., and enough used so that the mixture will be compact when rolled. The sand and gravel should be well heated before the tar is added. Often a 4 to 6-inch base of Portland cement concrete takes the place of the tar concrete. When cement concrete is used, it should be given a coat of tar before the top course is laid. A layer of tar and sand mixed in the proportion of fifty or sixty gallons of tar to each yard of sand and heated to 225° F. is spread over the base to a depth of 1¼ inches and rolled down to a thickness of 1 inch. Plank 3 inches thick is embedded in the sand and tar while it is still warm and soft, and a top or wearing floor laid on the plank.

If it is desired, an ordinary concrete floor may be used in basements. Such a floor has a base similar to that described for the block floor, covered with a layer of 1:2:4 Portland cement concrete 4 inches to 6 inches thick and finished with a wearing coat of cement and sand. This top coat is usually from 1 inch to 2 inches thick and composed of a 1:2 mixture of cement and sand. Top should be kept wet for at least ten days after laying.

Floor Loads, Working Stresses, Etc.

Allowable floor loads, working stresses to be used in design, weights of merchandise, and weights of timber will be found in a separate section at the end of this bulletin.

CHAPTER IV.

POSTS OR COLUMNS.

General Construction The posts or columns in mill construction serve as interior supports for the floor and roof girders and carry the loads to the foundations. Each set of posts should extend from roof to foundation without offset, passing through each floor between the ends of the girders for that floor, and resting upon a metal cap on the top of the post of the floor below. The ends of posts should be squared and bear evenly upon the plate of the post cap. At the foundation or pier, the squared end of the timber post should rest on a metal plate placed on top of the pier a little above the level of the basement floor to prevent contact with dampness from the masonry or concrete. A preservative treatment applied to the ends of the post is advisable if dampness is likely to be present.

Post Caps and Pintles The general alignment of the columns is preserved by the floor and roof girders which rest upon side brackets projecting outward from the post cap. Figs. 8 to 10 show a few of the types of metal post caps which are in use in different parts of the country.

Fig. 11 shows a type of pintle and post cap which is used to a considerable extent in the New England States and is recommended by the Associated Mutual Fire Insurance Companies. It should be noted that where no straps are used on the girders, or where post caps without projecting

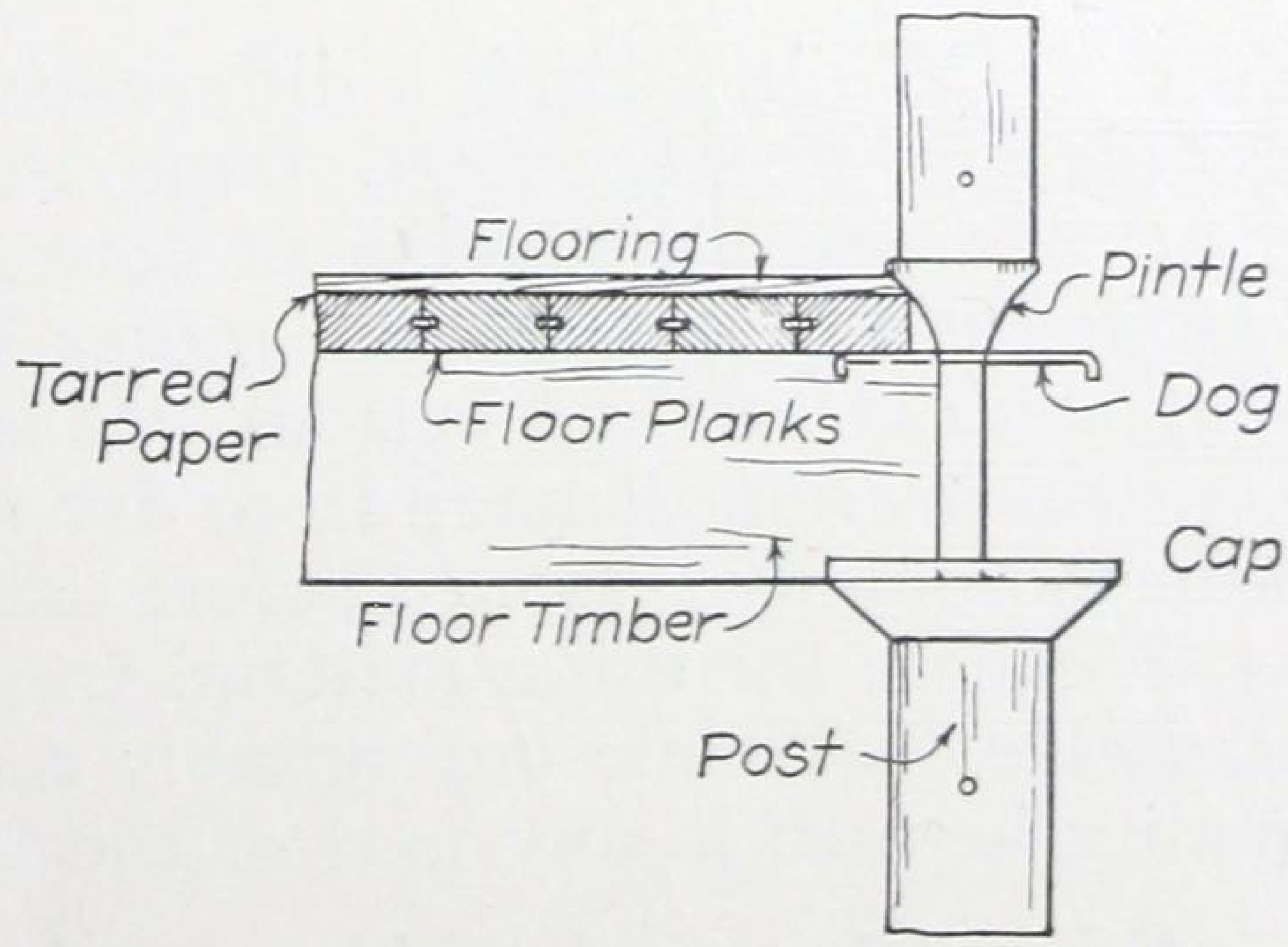

Fig. 11. Pintle and Post Cap Type of Construction.

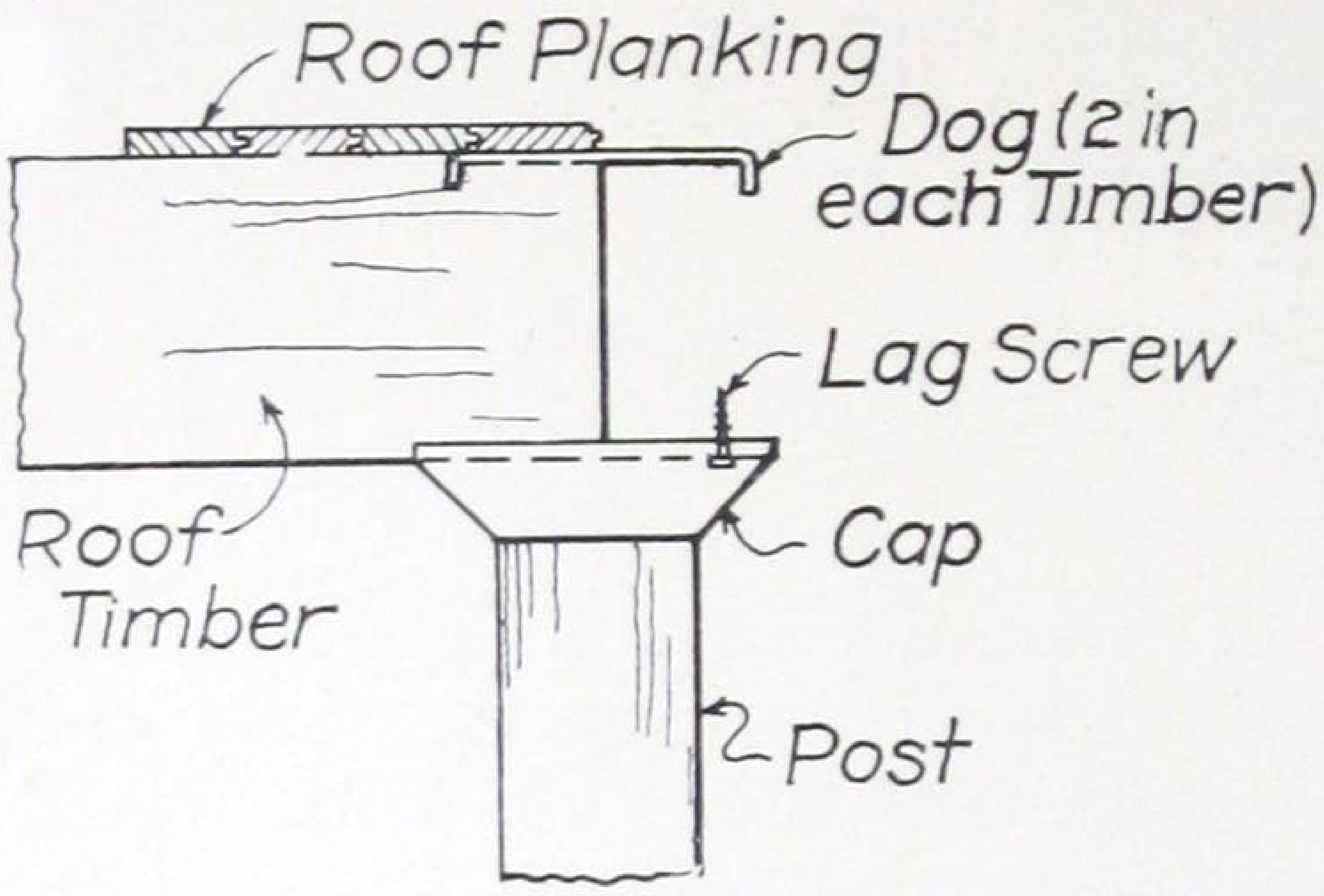

Fig. 12. Framing at Roof.

sides are used, the girders are tied together longitudinally by 1-inch iron dogs placed as shown in Fig. 11. The detail at the roof where this type of construction is used is shown in Fig. 12.

The supporting plate on a post cap should be of such size that the girders will have a bearing of at least 5 lineal inches at each end, and the end of the plate should not extend more than 6 inches beyond the post.

Minimum Sizes Minimum sizes of timber for columns vary from 8 inches by 8 inches in top story, to 10 inches by 10 inches in any story, depending upon the ordinances of different cities. In any event, the area of cross-section should be sufficient to carry the load with a suitable factor of safety, and also provide fire resisting qualities. Square posts of a given size are nearly one-fourth stronger than a round post turned from the same timber.

Many ordinances in a measure control the size of posts by limiting the length of a post of a given side dimension. The Chicago Building Ordinances state that no timber post shall be longer than thirty times its least side dimension.

Post Details While there is a difference of opinion as to the value of boring posts, some insurance engineers recommend the practice of boring a $1\frac{1}{2}$-inch diameter hole longitudinally through the center of the stick, with $\frac{1}{2}$-inch vent holes at top and bottom. It is claimed that this precaution will prevent damage from dry rot in timber which has not been thoroughly seasoned before using. This should not serve as an excuse for using material fresh from the saw, since it is advisable that none but suitably seasoned timber of the best quality be used in any part of the framing.

Edges of posts should be rounded or chamfered to prevent easy ignition in case of fire. The post should be left square

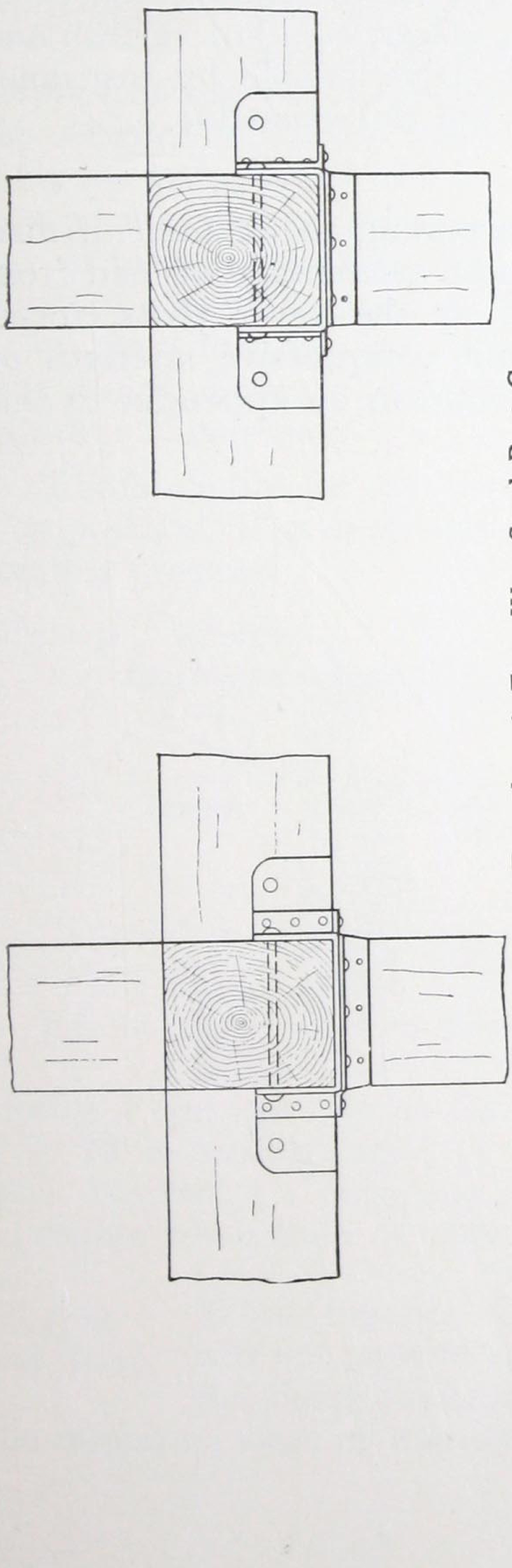

Fig. 9b. A Four-Way Steel Post Cap.

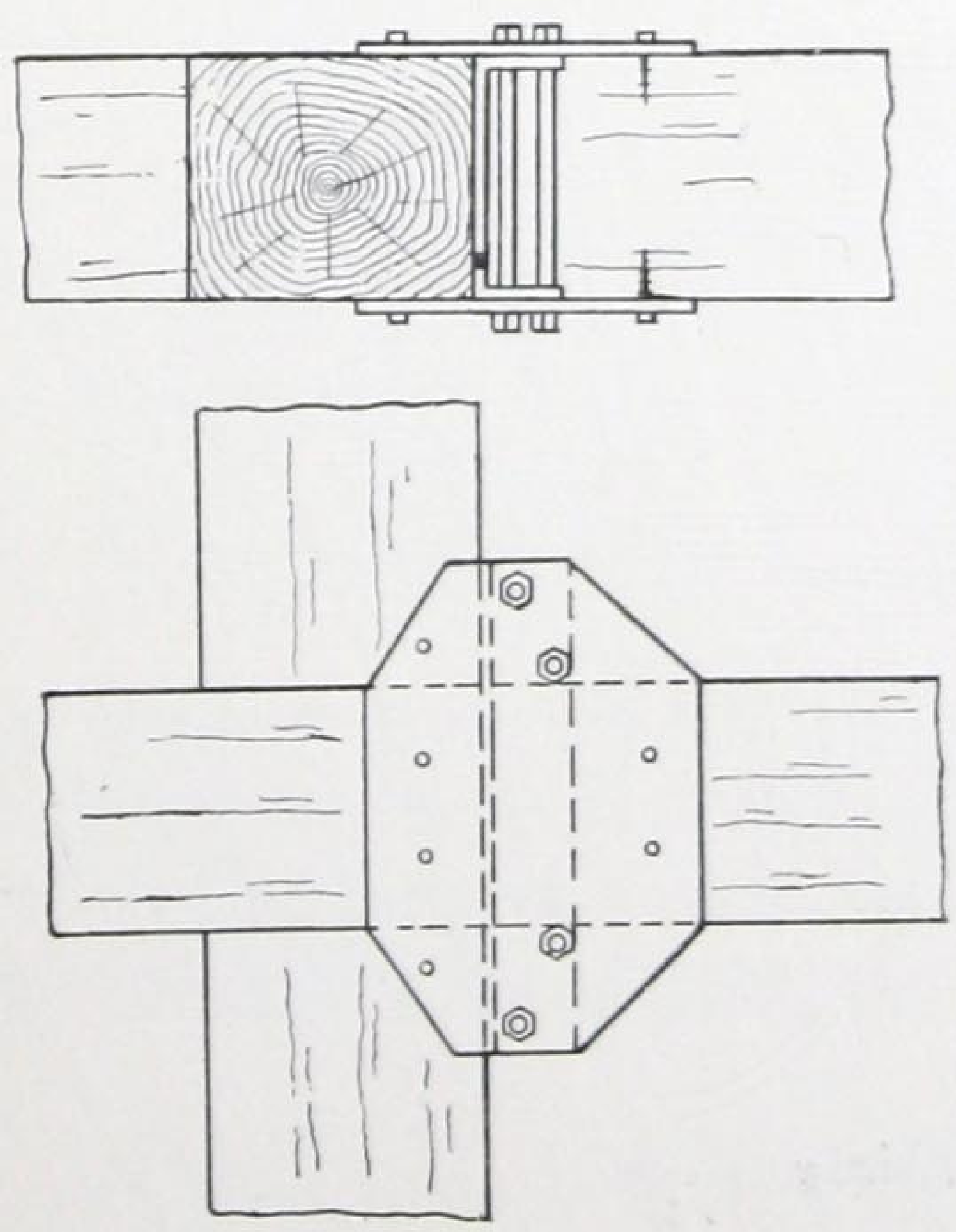

Fig. 10. Steel Post Cap with Side Plate.

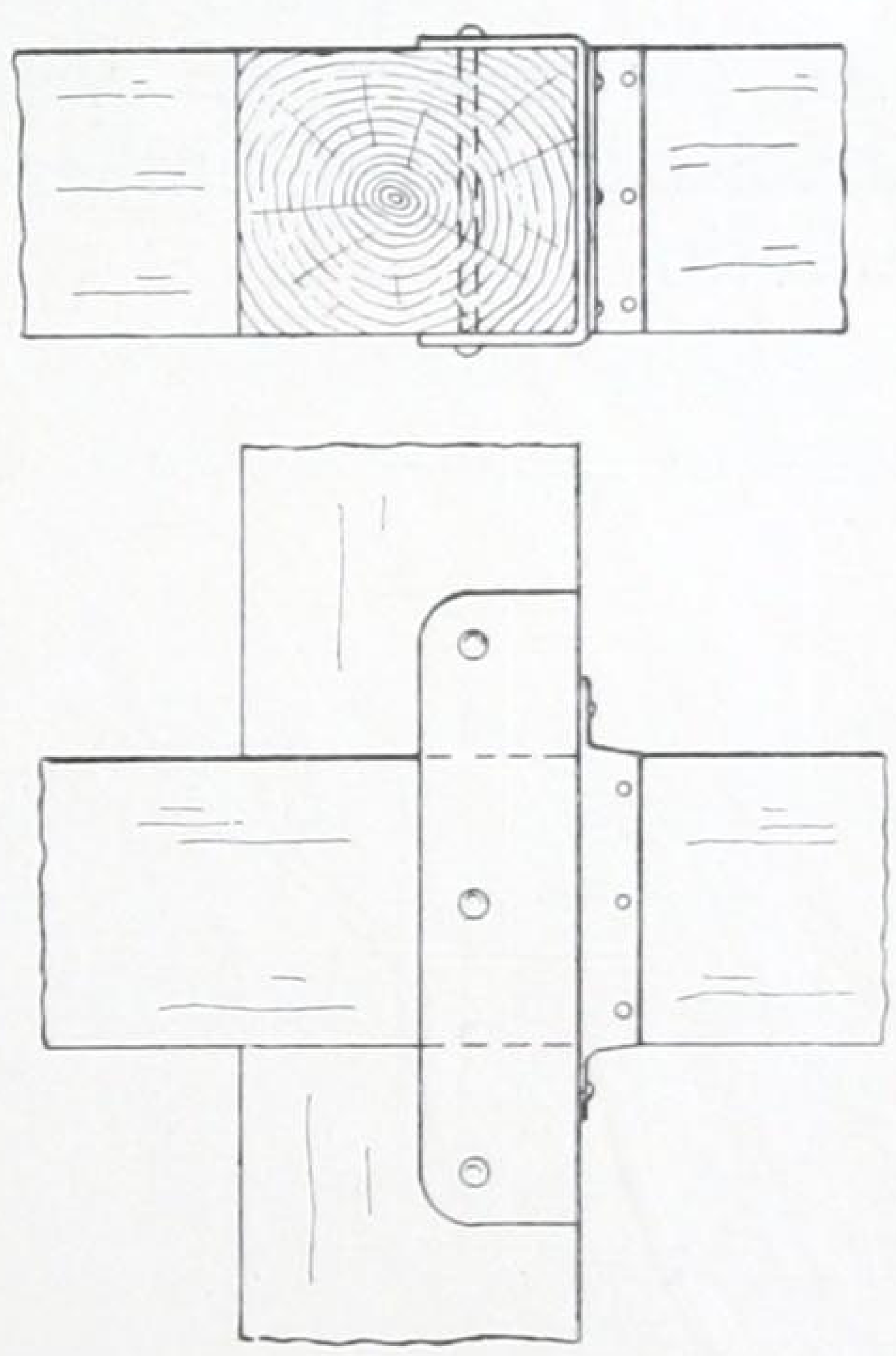

Fig. 9a. A Two-Way Steel Post Cap.

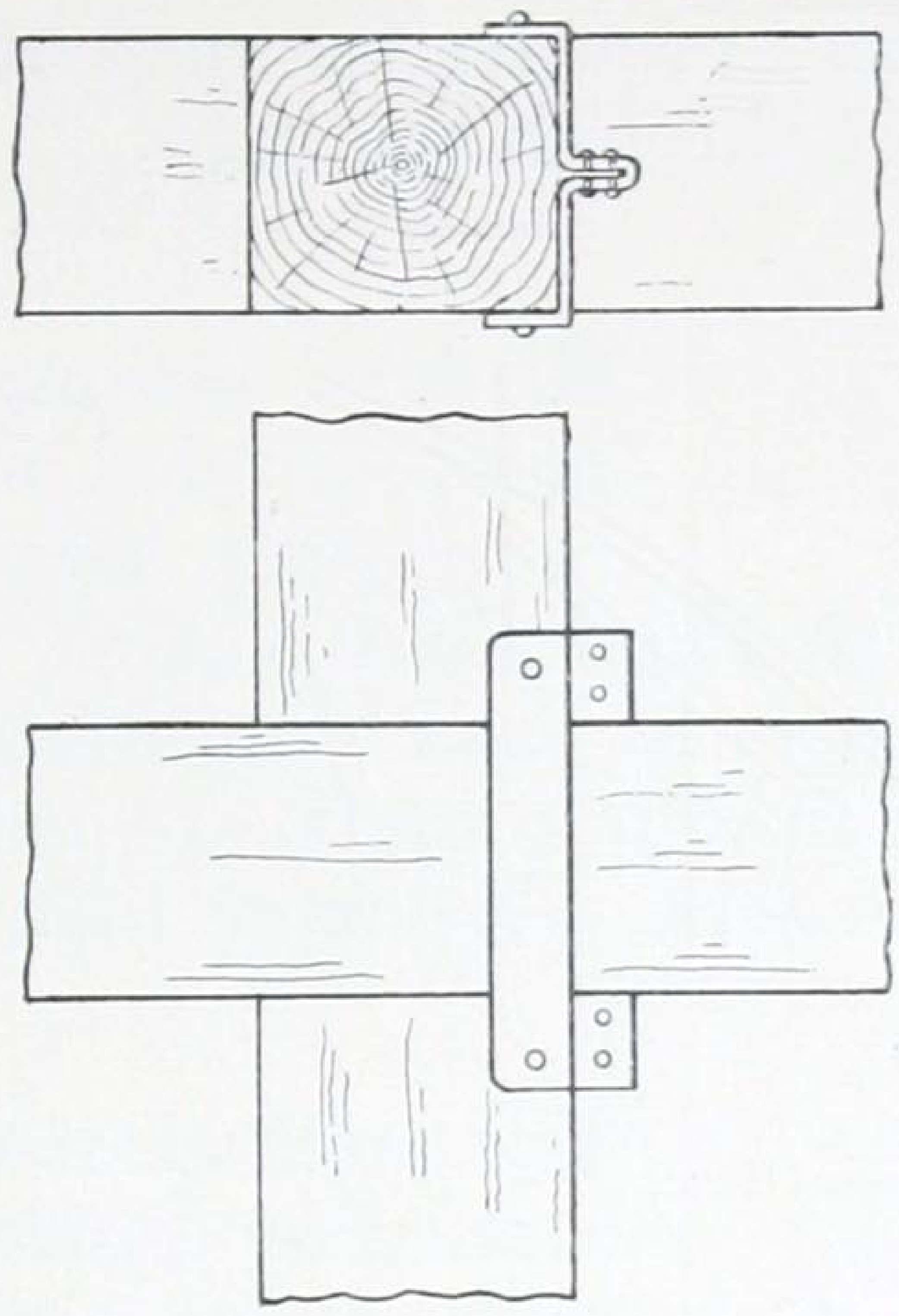

Fig. 8. Steel Post Cap with Fin.

near top to receive the post cap, and also at the bottom where it passes through the floor.

Finish on Woodwork Girders, beams, floors, or posts should not be painted, oiled or plastered until they have become fully seasoned. This time is usually between two and three years. Wood finish without concealed spaces may be used with safety in offices, etc., but varnish and shellac finishing coats are called objectionable by insurance underwriters. Ordinary paint is not objectionable.

Calculations For Posts The method of determining the amount of load carried by a given post, percentage of load from posts above carried by the lower posts, formulas for design of posts, and unit compressive strength of various kinds of timber will be found in an appendix to this bulletin.

CHAPTER V.

ROOFS.

General Construction Roofs in mill construction buildings are usually flat with a slight pitch of 1/4 inch to 3/4 inch to the foot. They are framed in the same manner as are the floors, the under side of the roof forming the ceiling for the top story. If a plastered ceiling is necessary, the metal lath which is to hold the plaster should be fitted around the girders and against the roof boards in such a manner as to leave no spaces between the plaster and wood. If plastering is to be used in contact with the timber, it should be of plain lime mortar without the skim coat of lime putty. The rough plaster is sufficiently porous to permit seasoning to continue if necessary.

Roofs should be covered with an incombustible material. Composition, slag or gravel roofing is used to a large extent for this purpose.

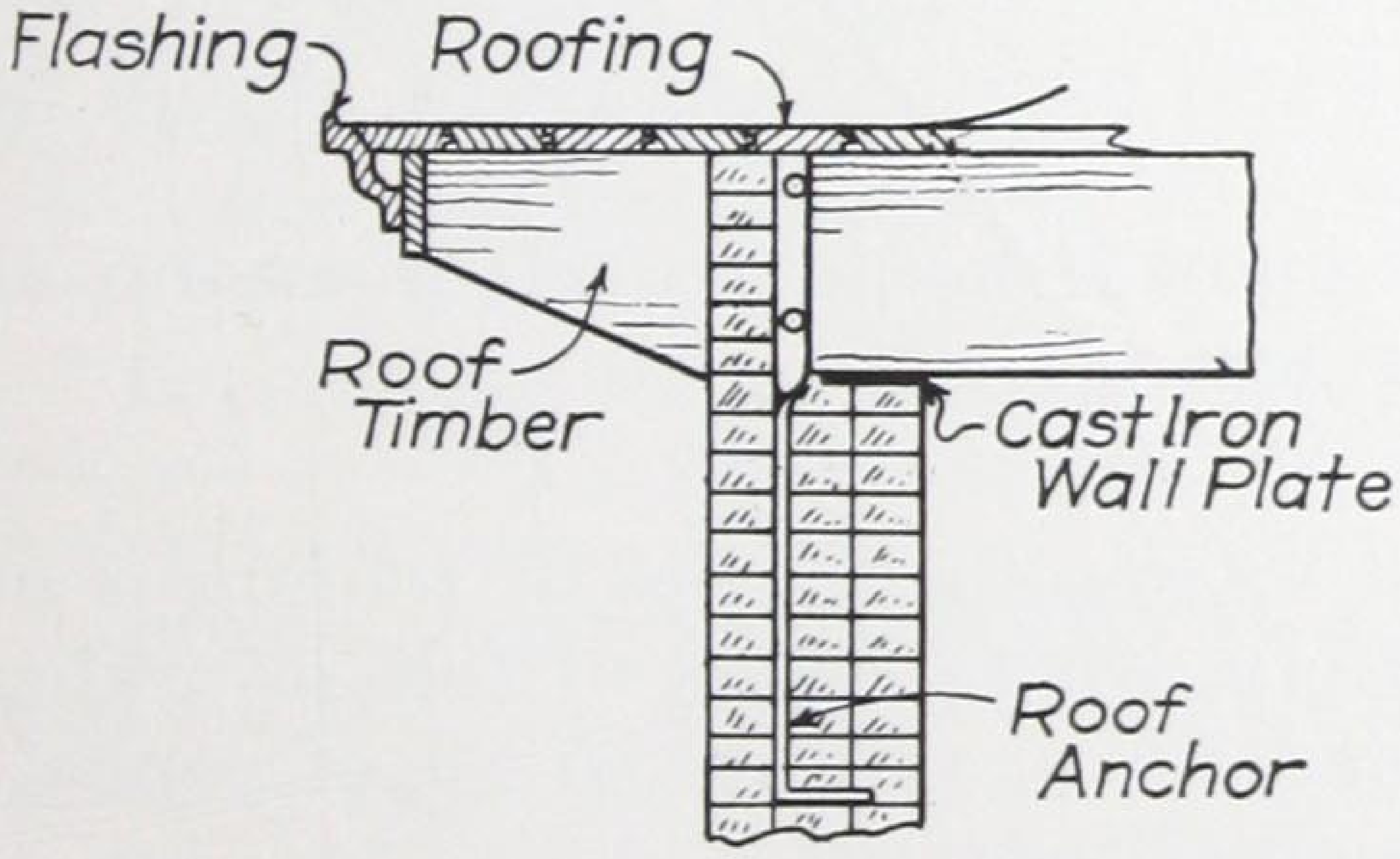

Fig. 13. Detail of Wood Cornice.

The necessity of a cornice is questionable, even from an architectural standpoint. It is a constant source of expense for maintenance and is likely sooner or later to become dangerous and fall without warning, due to the failure of concealed members. Providing a cornice is to be used, the open wood type shown in Fig. 13 is recommended by the Associated Factory Mutual Fire Insurance Companies, but an incombustible cornice is advisable when there is exposure from neighboring buildings.

Girders and Roof While the size of the girders to support the roof will not need to be as large as those for supporting the floors on account of the lighter loads carried, the minimum sizes of material permitted will control the size

of girders to be used. In many cases this dimension is regulated by the local building ordinances, and an inspection of such ordinances will show that sizes vary in different communities. From the standpoint of fire protection, the smallest roof girder that should be used is at least 6 inches in either dimension, but the common building regulation is that such girders should be at least 6 inches thick and have a cross-section area of at least 72 square inches. This same regulation in regard to minimum sizes should apply to beams in semi-mill construction, as well as to the girders in standard construction.

The size of the bays in the roof will be determined by the size of the bays of the floors below.

In many cases a roof of semi-mill construction type is placed on a building in which all of the floors are of standard mill construction, or of laminated type. This design is not necessary, since a certain minimum thickness of roof plank is demanded regardless of the load to be carried, and the thickness of 3 inches commonly specified is sufficient to support ordinary roof loads with the lengths of span between girders commonly found. A simple calculation will show this point to be true, especially where a good grade of lumber is used. Roof plank 3 inches in thickness may be tongued and grooved, but with a thickness of 4 inches and over splined plank should be used.

Both roof timbers and planks should be self-releasing at walls, and have exposed surfaces planed.

Roof Covering

One of the most satisfactory types of roofing is of the built-up variety, where layers of felt saturated with tar are nailed down, and by the use of asphalt or pitch protected and cemented together.

The following specification quoted from a Report of Railway Maintenance of Way Association gives what is considered to be good practice in the construction of a flat built-up roofing on wood sheathing:

SPECIFICATION FOR FELT, PITCH AND GRAVEL OR SLAG ROOFING OVER BOARDS

Incline.—This specification should not be used where roof incline exceeds three (3) inches to one (1) foot.* For steeper inclines modified specifications are required.

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*Modern practice tends to reduce this slope to 2 inches to 1 foot.

Specifications

ROOFING.—First, lay one (1) thickness of sheathing paper or unsaturated felt, weighing not less than five (5) pounds per hundred (100) square feet, lapping the sheets at least one (1) inch.

Second, lay two (2) plies of tarred felt, weighing fourteen (14) to sixteen (16) pounds per hundred (100) square feet, lapping each sheet seventeen (17) inches over the preceding one, and nail as often as is necessary to hold in place until remaining felt is laid.

Third, coat the entire surface uniformly with straight run coal-tar pitch.

Fourth, lay three (3) plies of tarred felt, lapping each sheet twenty-two (22) inches over the preceding one, mopping with pitch the full twenty-two (22) inches on each sheet so that in no place shall felt touch felt. Such nailing as is necessary shall be done so that all nails will be covered by not less than two (2) plies of felt.

Fifth, spread over the entire surface a uniform coating of pitch, into which, while hot, imbed not less than four hundred (400) pounds of gravel or three hundred (300) pounds of slag to each one hundred (100) square feet. The gravel, or slag, shall be from one-quarter (1/4) to five-eighths (5/8) inches in size, dry, and free from dirt.

FLASHING.—Flashings shall be constructed as shown in detailed drawings.

LABELS.—All felt and pitch shall bear the manufacturer's label.

INSPECTION.—The roof may be inspected before the gravel or slag is applied by cutting a slit not less than three (3) feet long at right angles to the way the felt is laid.

N. B.—To comply with the above specifications, the material necessary for each one hundred (100) square foot of roof is approximately as follows: 100 square feet sheathing paper, 80 to 90 pounds tarred felt, 120 to 160 pounds straight run coal-tar pitch, 400 pounds gravel, or 300 pounds slag.

In estimating felt the average weight is practically fifteen (15) pounds per one hundred (100) square feet, and about ten (10) per cent extra is required for laps.

In estimating pitch the weather conditions and expertness of the workmen will affect the amount necessary for the moppings and to properly bed gravel or slag.

The sheathing paper or unsaturated felt is placed on the bottom next to the roof boards, mainly to keep any pitch which might penetrate the two-ply felt above it from cementing the roofing to the sheathing. It also is of value in preventing the drying out of the roof through open joints from below. The saturated felts should be nailed where there is any chance of disturbance of the roof from underneath by wind, and also enough to hold it in place while laying. The practice in regard to nailing varies in different parts of the country, but the fewer nails the better, so long as the roof is held in place.

The contract price for this roof should not be less than the cost of the materials specified, plus the cost of laying and a reasonable amount for profit. Thorough inspection of materials and workmanship is recommended.

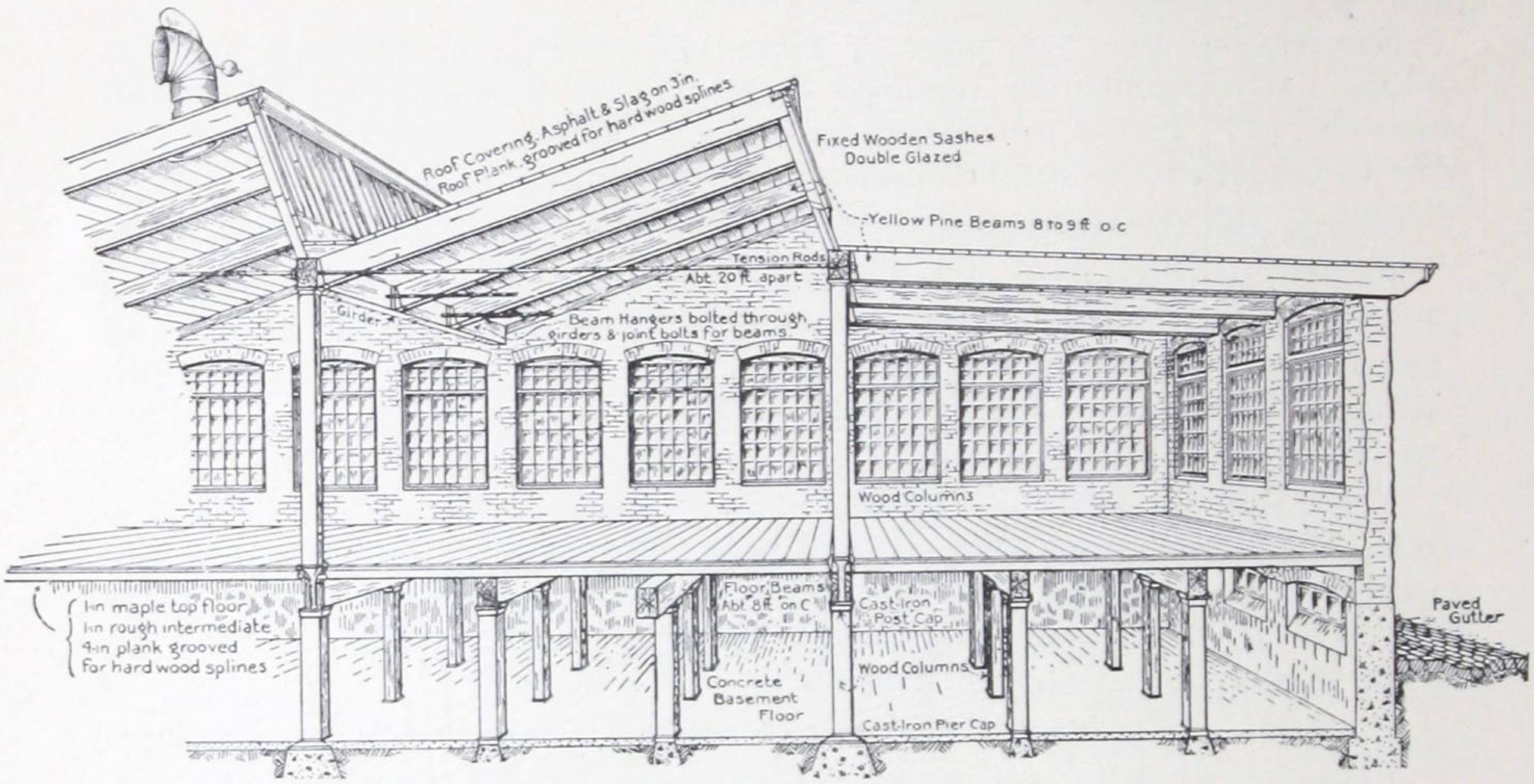

Fig. 14. Saw-Tooth Roof of Timber Construction.

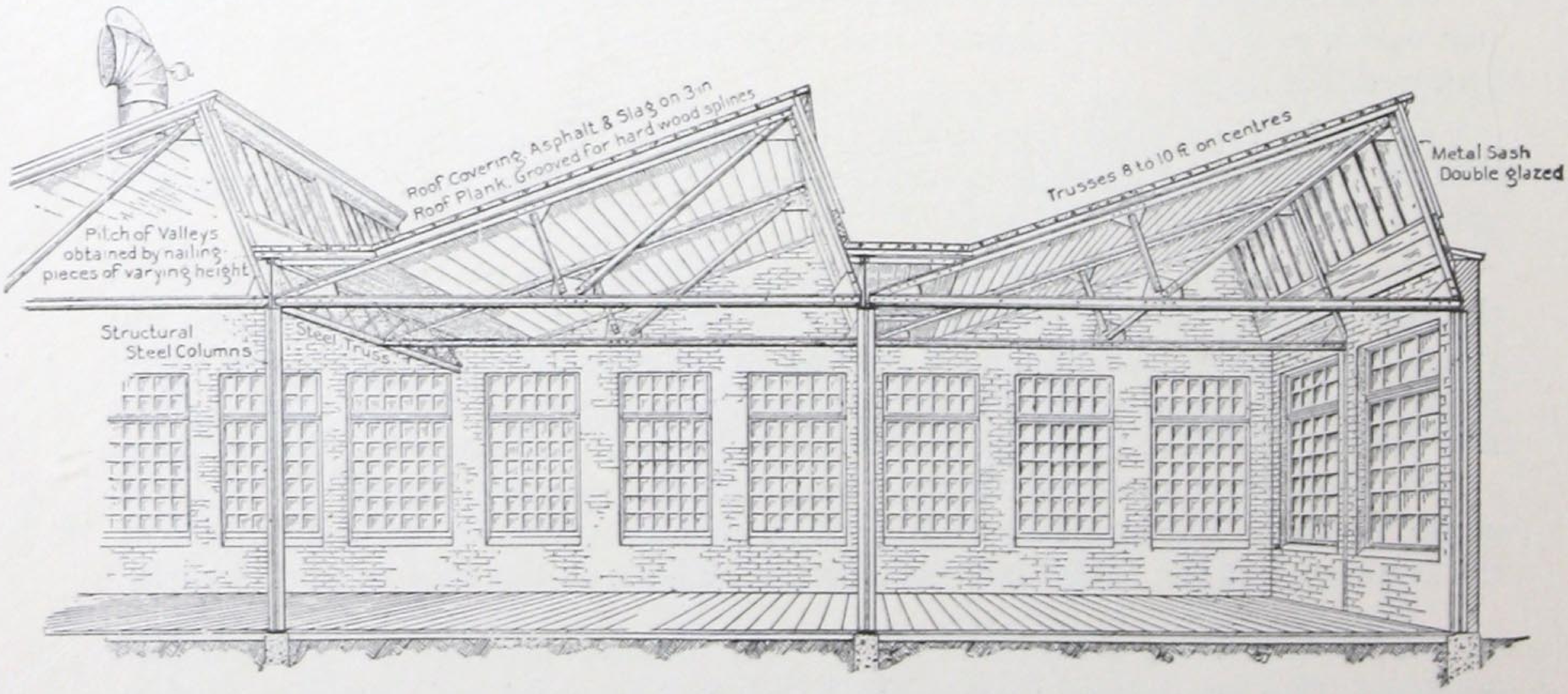

Fig. 15. Steel Framing with Plank Roof.

Trussed Roofs In many types of commercial buildings open spaces without posts are desired. This condition is very likely to exist in manufacturing plants where large areas of clear floor are necessary for the movement of machinery or assembling of machine parts. In such buildings the posts are taken out and roof trusses used to span the opening. Trusses are ordinarily placed from 8 feet to 20 feet on centers with 3-inch plank spanning the distance between the trusses as in standard mill roofs, or resting on purlins spaced not less than 8 feet on centers and running from truss to truss. It is advisable to have the purlins supported at the joints of the trusses to prevent bending in the members of the top chord. Other details of the roof are similar to those described above.

Saw-Tooth Roofs Where a saw-tooth form of roof is needed, the roof planks are supported by heavy timber beams, or by steel trusses, spaced from 8 feet to 10 feet on centers, and in turn carried by timber girders, trusses, or columns. In fact, the design of the roof planking itself varies but little from that used in the ordinary flat roof of standard mill construction. The detail of the supporting members will vary with the type used. Figs. 14 and 15 show two forms of saw-tooth roofs, one wholly of timber construction and the other of timber and steel. Fig. 16 shows a detail of the valley used in timber construction, such as shown in Fig. 14. These details are as recommended by the Associated Factory Mutual Fire Insurance Companies.

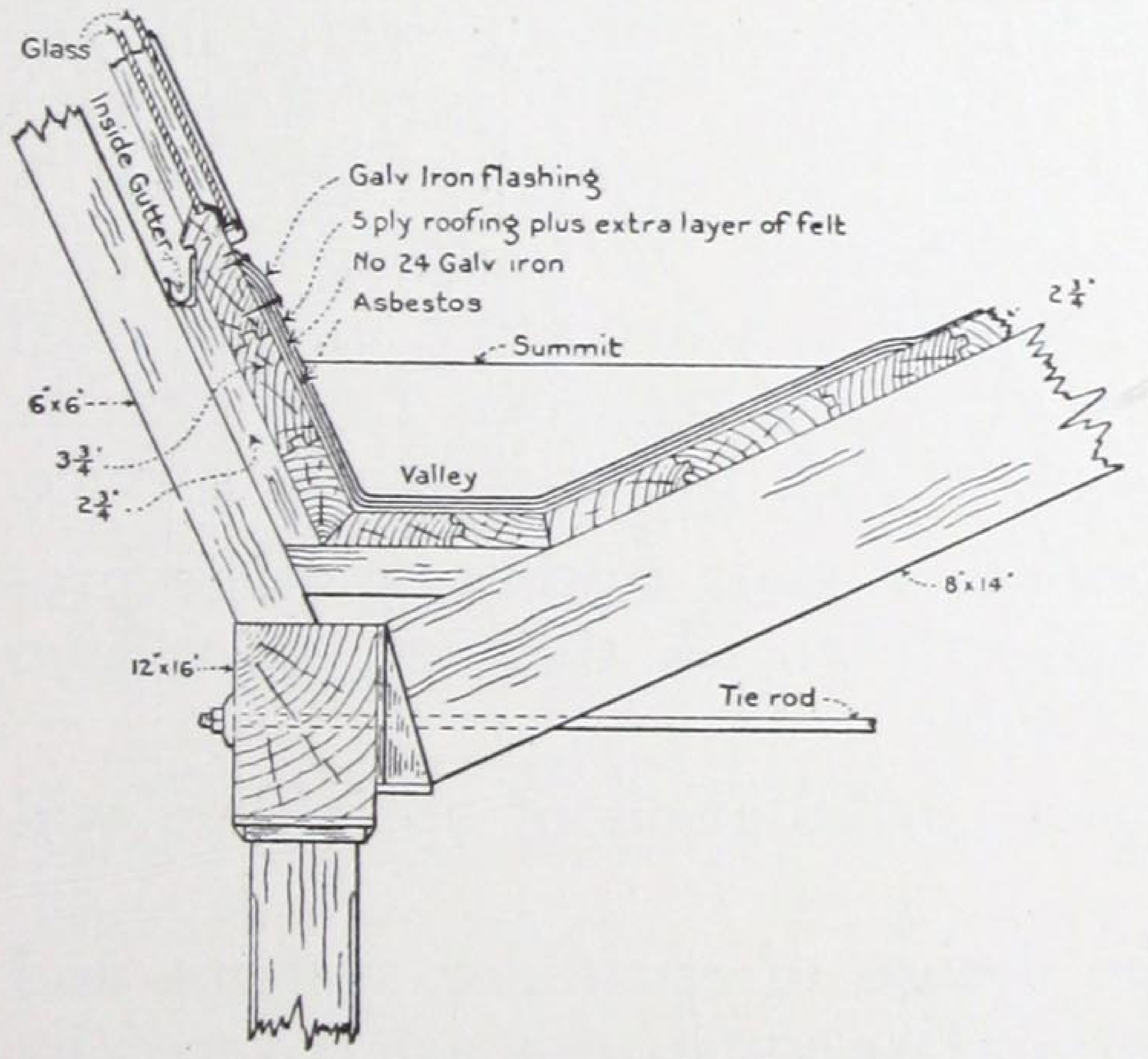

Fig. 16. Detail of Valley.

CHAPTER VI.

FIRE PROTECTION.

A building can be protected from damage by fire from exterior sources by the use of fire-resisting shutters or wire glass in steel or hollow metal frames at the windows and openings, together with an incombustible cornice. Thick party walls, and parapet walls extending not less than 3 feet above the roof line form additional safeguards. Fires occurring within a building may be confined to a limited space by the use of fire walls, heavy timber floors without openings, enclosed stairways, automatic fire doors, protected openings into power and elevator shafts, protected windows near angles of the building, and incombustible interior walls which extend through the roof for a distance of 3 feet or over. The installation of an automatic sprinkler system of a design capable of reaching fire in any part of the building and supplying water in sufficient quantities is always advisable. Not only does such equipment serve as a protection from spread of fire, but it allows also a lower insurance rating on the building and contents. A dependable water supply is a necessity, and at least two independent sources are generally provided from gravity tanks, pressure tanks, pumps or high pressure street service.

Standpipes and hose located in stair towers or other protected places offer additional safety. A steamer connection on exterior of building is advisable.

Suggestions for the typical installation of sprinklers will be found on page 47.

Details in regard to the design of sprinkler systems and the arrangement of other protective apparatus are covered by a special bulletin issued by the National Lumber Manufacturers Association.

Stairways and Elevator Shafts Vertical openings through buildings have proved to be the weakness which led to the destruction of many otherwise good buildings. All doors and openings into stairways or elevator shafts and between units should be provided with fire doors. These doors

should be made automatically self-closing by means of springs or weights and chain. Doors should never be blocked open, even temporarily. Where it is necessary to allow a door into a stairway to stand open, it should be held open by some simple automatic mechanism, arranged to release the door and allow it to close when fire occurs. Stairs may be of timber construction if the building is equipped with an automatic sprinkler system and stairs are enclosed in a fireproof wall.

The proper design of walls for stairways and elevators was discussed in Chapter II.

Shutters and Wire Glass

For severe or dangerous exposures it is desirable that all openings in exterior walls should be protected by tin clad, solid steel, or sheet-metal shutters. Shutters should overlap the sides and top of the window opening or close into the opening, so as to prevent cracks through which fire might pass. Modern practice has determined that steel or hollow metal wire glass windows are substantial in construction, and practical under most conditions of exposure. Such windows furnish a fair degree of resistance to fire, and where the exposure is not severe, they will prevent the spread of fire from one building to another, or one story to another in the same building. Two types of windows are commonly used—"steel sash" made of rolled steel sections, and hollow metal sash and frames made of galvanized sheet metal or copper of suitable gauge, reinforced by steel bars and angles. Wire glass is used in both of these types.

The fire-resisting qualities of mill construction are exemplified by the following extract from "Fire Prevention and Fire Protection" by J. K. Freitag:

> "A wonderful illustration of the slow-burning qualities of slow-burning construction was afforded by the fire which destroyed the storage warehouse of the George Irish Paper Corporation, at Buffalo, N. Y., Jan. 16, 1911. The building was six stories in height, 70 by 200 feet in area, and of mill construction without sprinklers or other special fire protection equipment. Because of the type of construction of the building, and the great weight of the paper stock known to be stored therein, the firemen flatly refused to enter the structure, so that the flames were fought entirely from the outside. The fire raged for upwards of 80 hours and was the longest fire known in the City of Buffalo, yet after 36 hours of fire the front windows in the top story were practically intact. No better example of 'slow-burning' construction could possibly be given."

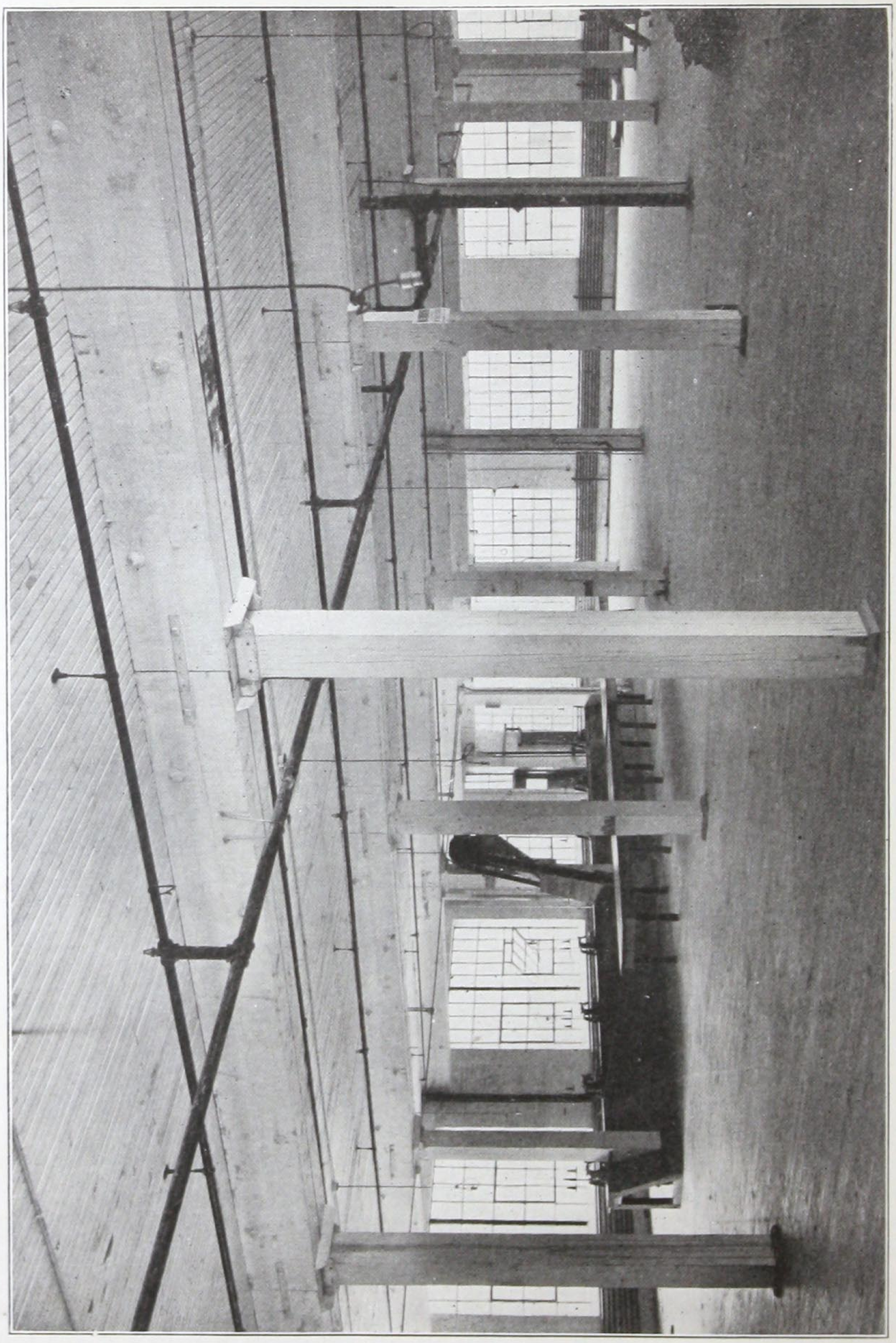

Fig. 17. Interior of Modern Mill Construction Building.
(Central Bag Mfg. Co., Central Mfg. District, Chicago. S. Scott Joy, Architect.)

CHAPTER VII.

COST OF MILL CONSTRUCTION BUILDINGS.

One of the important advantages of mill construction is the relatively lower cost when compared with other types of buildings. This feature has been recognized from the early days of this type of construction. With the advance in the cost of building materials as a whole, the relative difference between timber, steel and concrete has changed slightly in favor of concrete, but the advantage as a whole is still on the side of mill construction. The old custom of using girders 45 feet in length and spanning three bays of a building has passed, but the same strength is now obtained by using shorter lengths of larger material of a high bending strength. Large timbers of great strength in proportion to weight are obtainable in all markets, and there is an ample supply of all sizes and grades in several different species.

Mill construction buildings vary in cost with the locality in which they are built. The cost per cubic foot will vary from 5c to 12c, with an average of about 8c. These costs are without the consideration of plumbing, heating, elevators or other equipment. Such extras will increase the cost per cubic foot by 1c or 2c. The corresponding cost per square foot of floor area of building is from 50c to $1.50, with an average cost of about 90c. In order to obtain these reasonable costs, standard lengths and sizes of timber should be used, or else an extra amount will have to be charged for specials. The cost of such buildings may be kept to a minimum by careful decision in choosing length of spans and areas of floors. Each girder and floor plank should be used to its full capacity, as determined by the load rating of that floor. Areas of floors should be such that fire walls will not be needed between the different parts of a floor, thus keeping down the cost for protection of openings between rooms. A careful choosing of the sizes of bays will aid in the design of the sprinkler piping by making one or two lines of sprinklers do the work where more piping might be needed in case the spans were chosen without attention to this detail.

An investigation conducted by J. Norman Jensen, Architectural Engineer, Chicago, showed that the range of costs in the three types of construction is so great that no generalization can be made. By comparing the costs of a large number of different types of construction the following conclusions were reached:

"With column spacing not exceeding 16 feet, mill construction buildings designed for 100 pounds per square foot live load cost 20% less than concrete buildings; for 150 pounds per square foot live load, 15% less, and for 200 pounds per square foot live load, about 10% less. When the live load was 350 pounds per square foot or over, a concrete building was the cheaper."

This investigation showed also that when the column spacing in any building is greater than 16 feet, the relative economy of mill construction disappeared. It has been found, however, that a column spacing of 16 feet is ample for the majority of buildings devoted to manufacturing or other mercantile businesses. For most light manufacturing buildings a live load of 100 lbs. per square foot is sufficient, and for a large percent of the buildings used for storage purposes, 200 lbs. per square foot is all that will ever be placed on the floors.

An investigation in regard to the cost of insurance on mill construction, steel and concrete buildings showed that in ordinary lines of business the rate of insurance on a sprinklered mill construction building and contents runs about 25 cents per $100.00, while the rate on a concrete building and contents unsprinklered runs about 45c. The rate on both types of construction sprinklered is about the same, but the cost of installing the sprinkler system in the concrete building may make the total cost higher in comparison with a mill construction building.

The unit cost of a building varies considerably with the height of the structure. In connection with this point the following extracts from "Mill Buildings" by H. G. Tyrrell is of interest:

"Mill construction buildings of one and two stories cost more than buildings of three to five stories, the last being about 15% less per square foot of gross floor area than when all floor space is on the ground. For light products, it is, therefore, economical to make manufacturing buildings not less than three stories in height, for not only is the building itself less expensive, but it also occupies smaller ground space. The only possible reason that might cause the owner of a building for light manufacturing purposes to select one floor in preference to three or more would be the relative con-

venience and economy of carrying on the work on a single floor. Records of certain factories show that the cost of labor is from 5% to 10% less when work is all done on a single floor rather than on several floors."

A further comparison of the cost of wood, reinforced concrete and steel buildings is made by Mr. Tyrrell in his book "Engineering of Shops and Factories," as shown by the following extracts in which A is the greatest cost and G the least:

"Building types, arranged in order of their relative first cost, are as follows:

A. Complete steel frame, fire-proofed, with curtain walls and plank floor.

B. Interior steel frame, fire-proofed, with solid brick walls and plank floor.

C. Complete steel frame, fire-proofed, with curtain walls and reinforced concrete floors.

D. Interior steel frame, fire-proofed, with solid brick walls and reinforced concrete floors.

E. Entire reinforced concrete building.

F. Part interior steel frame, not fire-proofed, with solid brick walls and wood mill floors.

G. Entire wood mill construction.

"In comparing the first cost of buildings in wood mill construction and in reinforced concrete, it will be found that their relative cost varies with the location, size of building and the floor loads to be sustained. In the Southern states, or other regions where timber is abundant and cheap, wood construction will often cost 25% to 30% less than reinforced concrete, while in districts where wood is scarce, the two types may be nearly equal. The comparison depends also on the size of the building, for large ones have often been found to cost about the same in either material, and small ones are sometimes more expensive by 30, 40 or 50% in reinforced concrete than in wood. The required floor capacity also affects the comparison. Light loads with long spans are cheaper in wood mill construction than in reinforced concrete, the cost of the two types being nearly equal in large buildings with 200 pounds imposed loads per square foot, and column spacing of 18 to 20 feet. With loads of 300 to 500 pounds per square foot concrete becomes cheaper, and the saving increases rapidly with greater loads of 1,000 to 1,200 pounds per square foot."

The following extracts taken from an address delivered before the Portland members of the West Coast Lumbermen's Association by C. J. Hogue, Architect, Portland, Oregon, are of interest since they provide comparative data from that section of the country.

"As a result of twelve years' experience in New England I saw reinforced buildings (I am speaking from the standpoint of an engineer), concrete buildings constructed for within 5 to 15 percent of the cost of mill construction, and structural steel buildings at 10 to 25 percent additional cost. Of course in the cheaper types of wood construction there were more differences than

with an engineering type. At that time the cost for mill constructed buildings would have shown a greater difference than I found for reinforced concrete. As a matter of fact we could not obtain low enough rates in insurance on sprinklered re-inforced concrete buildings over sprinklered mill construction to pay the difference in the interest on cost of the two types of buildings.

"Since my return to Portland I have been ostensibly practicing economy, so I can not give you the best of comparisons from my experience. But in the recent effort to relieve building conditions in the inner fire district, which resulted in eliminating one-third from the inner into the outer district, we took comparative figures on two buildings, one mill constructed and one of reinforced concrete. The two buildings were to cover an area of 100 by 100 —plastered throughout, as if they were to be used for retail stores. The figure we received, without heating, lighting, plumbing and elevator, for mill construction was $27,135 against $37,651 for the reinforced concrete building, an additional cost of 37 per cent. To those figures, add $6,000 to both buildings for plumbing, etc., and the additional cost of the reinforced concrete building was 31.7 percent more than the cost of the mill constructed building. This is because lumber is cheaper in the West than it is in the East, and cement, sand and gravel are much more expensive.

"Now the best comparison of safe types of fire resisting construction can perhaps be shown by the comparative insurance rates—from the judgment of men whose business it is to study this question. We in Portland have secured comparative insurance rates—assuming occupancy of a furniture store and the rate on the wood construction building was 47 cents and on the fireproof building 35 cents and with sprinklers the comparison was 28 cents on the mill and 21 cents on the fireproof. The rate was made on the building, not on the contents. The rate for the mill constructed building, sprinklered, 28 cents, was less than on the unsprinklered fireproof building, 35 cents.

"I also had copies of fire rates from the Chicago Board of Fire Underwriters, assuming a machine shop occupancy. The rate on a building not sprinklered, mill construction, was $1.11, as against 24 cents for fireproof construction; and sprinklered, 15 cents for mill construction as against 14 cents for fireproof material. The comparison between the sprinklered mill construction building shows 15 cents as against 24 cents for the non-sprinklered fireproof building; and where both are sprinklered only 1 cent difference, 15 cents for the mill construction and 14 cents for the fireproof. On the contents, the rate on non-sprinklered mill construction was $1.36 as against 64 cents for the fireproof; the rates on the contents of sprinklered building were 30 cents for the mill as against 26 cents for the fireproof building. The comparison there for the sprinklered mill constructed is 30 cents as against 64 cents for the non-sprinklered fireproof building. This shows clearly that a sprinklered mill constructed building is a safer risk from a fire insurance standpoint than one of non-sprinklered fireproof construction.

"The sprinklered mill constructed building is safer both as to building and contents than is a fireproof building, non-sprinklered. In the same way a mill constructed building with properly constructed stairways and elevator shafts is safer as to contents than the non-sprinklered unprotected stairway of a fireproof structure. Another thing is the temperature which runs from

1,000 to 1,200 degrees as compared to 1,800 degrees in fireproof non-sprinklered buildings. The steel columns almost invariably buckle early in the game and are of no further support to the building.

"I believe, from my experience in both kinds of construction, that the mill constructed building, masonry walls, wire glass windows, equipped with a sprinkler system, would have almost as great effect in stopping a conflagration as if the interior was of so-called fireproof construction, that is, incombustible materials."

CHAPTER VIII.

STANDARD MILL CONSTRUCTION.

This section illustrates the advantages of well-designed buildings and protective apparatus in the prevention of heavy losses by fire, as recommended by the Associated Mutual Fire Insurance Companies of New England, and shown in Report V, issued by the Insurance Engineering Experiment Station. Since this particular type of mill construction has been developed mainly to meet New England conditions, it follows that the references to the kind of timber apply more directly to the New England market than to other localities.

While modern practice as outlined in the earlier pages of this bulletin may vary in some details, this section serves as a summary. It also presents the subject from the standpoint advocated by the insurance companies responsible for the greater part of the development of this class of building.

This plate (Fig. 18) illustrates the best practice in construction of a storehouse more than two stories in height, intended for storage of raw stock or goods. The important features of the design, which should be kept in mind when applying them to special cases, are as follows:

Construction "The area of each compartment to be preferably 5,000 square feet but not over 10,000 square feet for non-hazardous storage; 5,000 square feet is the usual standard for cotton. The height of each story for cotton, or for other readily inflammable material, should be such as to permit the storage of but one bale on end—8 feet from floor to floor is generally sufficient. When designed for cased goods the height should be sufficient to take two cases, with 10 inches to 12 inches under the beams, in order not to impede the distribution of water from the sprinklers. Ample provision for passageways should also be made.

"The compartments should be separated from each other by solid brick walls and be accessible only from the elevator and stair tower, with the openings here protected by standard automatic sliding fire-doors. This will confine damage to the compartment in which a fire may start.

Walls "Brick walls should be at least 12 inches thick in the top stories and increased at the lower floors to support their additional load. The pilastered wall has many favorable features and may be preferred to the plain solid form.

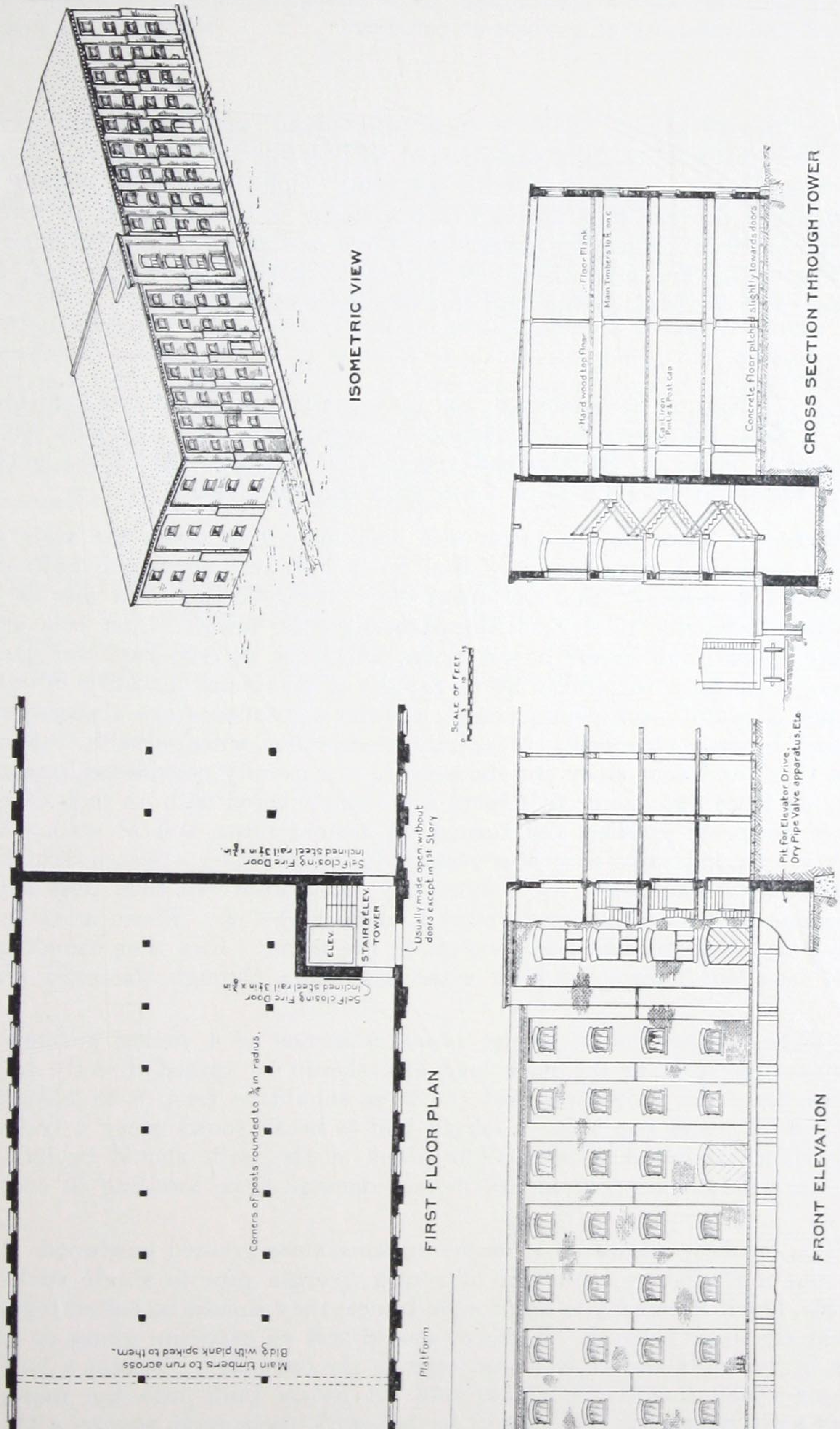

Fig. 18. Storehouse of Standard Mill Construction.
(Associated Factory Mutual Fire Insurance Companies.)

"Window and door arches should be of brick; window and outside door sills and underpinning of granite or concrete.

Roofs "Roofs should be of 3 inch pine plank, spiked directly to the heavy roof timbers and covered with 5-ply tar and gravel roofing. Roof should pitch one-half inch to the foot. Conductor pipes should not pass through the building unless the storehouse is to be heated in winter. An incombustible cornice is needed when there is exposure from neighboring buildings. The fire wall should be carried 2½ feet above the roof, and provided with vitrified coping laid in Portland cement mortar.

Floors "Floors on each story in the tower should be about one inch lower than the floors in the adjoining compartment. The sills should be sloped to make up for this difference in level. The sill of the outside door in the tower should also be lower than the tower floor.

"Water on floors in the tower will ordinarily flow down the stair and elevator shaft, and arrangement of floor levels indicated above will ordinarily prevent water coming from an upper floor from flowing into one of the lower compartments, if it is escaping through the tower. Cast iron scuppers are advised and should be set in the brickwork at frequent intervals, so designed that they will carry away rapidly a maximum quantity of water from the floors of each compartment. Water-tight floors are always desirable and become a necessity in certain storehouses with valuable contents, but in three and four story storehouses are not usually considered essential. In higher buildings one or two floors are often covered with an inch of rock asphalt, properly applied and turned up around posts and at walls about 4 inches. Considerable care is necessary in constructing a water-tight floor if satisfactory results are to be obtained. All water will then pass out at the scuppers and no damage is caused on floors below. There must be no vertical openings through floors except in the tower. Fire thus cannot gain access from one floor to another without burning through the solid plank floor.

"Floors should be of spruce plank 3 inches or 4 inches or more in thickness according to the floor load and should be spiked directly to the floor timbers. In floors and roof the bays should be from 8 to 10½ feet wide and all plank two bays in length laid to break joints every 4 feet and grooved for hardwood splines. The plank at the walls should be left out until the windows are put in, to prevent damage from swelling in case of rain.

"The top floor should be of maple or other close-grained hardwood. The floor and roof timbers should be of sound Georgia pine in single sticks, if possible, but if necessary to use double beams, they should be bolted together without air space between. Timbers should rest on cast-iron plates or beam boxes in the walls and on cast-iron caps in the columns. At least a half an inch air space should be left around all beams built into the masonry. Columns of Southern pine should be cut with their ends square with the axis.

"Windows may be of small area, but should be placed high in order to give the best light.

Protection "A standard equipment of automatic sprinklers should be installed throughout. In mild climates, and even under some conditions in cold ones, it is advisable to install a line of $1\frac{1}{4}$-inch steampipe overhead on each floor to provide sufficient heat to avoid freezing of the water in the sprinkler-pipes. If the building is not heated an air system with water controlled by an approved dry-pipe valve must be used, and all pipes must have $\frac{1}{2}$-inch pitch per 10 feet back to main riser to insure proper drainage. A dry-pipe valve chamber may be located in the basement of the stair tower. The number of sprinklers in one dry-pipe valve should preferably not exceed 300, and 400 is the maximum allowed under the rules. By heating the storehouse the expense of installation and maintenance of the dry-pipe system is avoided, and in buildings of this substantial character only a very small amount is needed, as it is only necessary to keep the temperature above the freezing point.

Standpipes "Standpipes are often advisable in the stair towers of the higher storehouses, and provision should be made below frost for draining them in cold weather, with a readily accessible indicator post gate for controlling the supply in case of emergency.

"Water supply to the sprinklers and standpipes, as well as for such outside hydrants as may be needed should be of good capacity from two independent sources."

CHAPTER IX.

QUALITY AND KIND OF TIMBER USED.

In order to obtain proper service from mill construction buildings, it is most essential that a good quality of timber be used. The special requirements for timbers which constitute good quality deal with their strength and lasting power. The strength of any timber will be determined by its weight or density; the size, quality and distribution of knots, and the presence or absence of defects. The density or dry weight of wood may be regarded as a measure of its strength. Taking timbers of yellow pine or Douglas fir as types, it should be noted that "each annual growth ring is composed of a band of dense, heavy, dark summerwood and a band of lighter, softer springwood. The greater the proportion of summerwood, the greater the weight and strength of the timber. The principle, referring to the number of growth rings and the proportion of summerwood as a measure of density and hence of strength, applies to all woods in which there is a marked contrast between the character of the springwood and the summerwood."*

As a result of extensive investigation made by the United States Government and the American Society for Testing Materials, a rule was adopted in 1915 which clearly specifies the manner for determining two classes of structural yellow pine timbers, one a high-grade quality called "dense pine" and the other a grade of lower strength value called "sound pine." The specifications for these classes‡ will be found in a booklet issued by the Southern Pine Association, New Orleans, La., entitled, "Southern Yellow Pine Timbers Including Definition of the Density Rule." A similar rule is now being prepared for Douglas fir, and in the absence of any accepted standard for Douglas fir, it will be safe to use the rule as drawn up for yellow pine.

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*Building Code recommended by the National Board of Fire Underwriters, page 282, 1915.

‡NOTE: These classes of timbers are defined in the 1915 Yearbook of the American Society for Testing Materials, pages 431 and 432, and were adopted by this Society August, 1915, and by the American Railway Engineering Association March, 1916.

Where maximum strength requirements are desired the quality dense pine alone should be specified and used, but where the strength requirements are not of the highest character the grade sound pine will be found sufficient.

The size, character and distribution of knots may materially affect the strength of any good timber, as indicated in the appendix to the suggested Building Code of the National Board of Fire Underwriters.

"The weakening effect of knots also depends upon their position, as well as their soundness, tightness, and the amount they distort the grain of the wood from a straight line. A comparatively small knot near the lower edge of a beam may be more harmful than a large knot located elsewhere. For example, a series of tests made upon loblolly yellow pine beams by the U. S. Forest Service, showed that the average strength of such beams with knots located in the bottom quarter of the middle half of the beams, was reduced 25% below that of similar beams with knots located in other portions. In such cases a knot near the neutral plane may act as a pin and serve to strengthen the beam against failure by horizontal shear.

"The number, character and location of defects in timber has much to do with its strength value. Checks and shakes in beams reduce the area which resist horizontal shear. Such defects are most harmful in the middle half of the height of a beam, as they are then comparatively near the neutral plane where their effect is greatest. The best place to judge of the effect of such defects is on the ends of the timber."

It should be noted that most timber specifications have explanatory clauses relating to the size of timbers as specified. The American Society for Testing Materials and the American Railway Engineering Association have adopted a clause which is used more or less universally, according to which rough sawed timbers should not be more than $\frac{1}{4}$ inch, nor dressed timbers more than $\frac{1}{2}$ inch scant of nominal size; that is, a nominal 12"x12" timber should not be less than $11\frac{3}{4}$"x$11\frac{3}{4}$" when sawed, or $11\frac{1}{2}$"x$11\frac{1}{2}$" when dressed.

The lasting power of timbers will be determined both by the kind and the quality of the wood used and by the conditions which obtain in the building in which it is employed. The timbers may have sapwood and heartwood in varying percentages. Sapwood is usually short-lived and where conditions are favorable to decay, will usually decay very rapidly. Heartwood, of practically all species, on the other hand, is comparatively long-lived. In buildings where the humidity is low such timbers usually last 25 and 30 years and longer when practically all-heart timbers are used. It is therefore of the utmost im-

portance that consideration be given to the relation between sap percentage of timbers and the kind of use to which a mill construction building is to be put. Where low or average humidity is to be expected, timbers having 85% heart will usually give splendid service; and where the humidity is higher, the timbers should either be all heart or, in case sapwood is used, such timbers should be preserved either with a good quality of coal-tar creosote or, where this for various reasons may be objectionable,, either with corrosive sublimate (usually known as the Kyanizing process) or with zinc chloride (usually known as the Burnettizing process). The presence of unlimited amounts of sapwood on timbers, which are to be used in buildings with high humidity, is strongly condemned. No amount of superficial painting with preservatives will be of any value.

Where untreated timbers are used, it will frequently be found advantageous to paint the ends and bearing surface of any timbers where they come in contact either with other timbers, with stone walls, metal or concrete surfaces. In such cases a high grade quality of distillate coal-tar creosote should be employed.

In the general selection of kinds of timber, yellow pine and Douglas fir will be usually specified for the stress bearing members such as girders and posts, this selection being based on the availability, suitability and cost of these woods. Consideration should also be given to white, Norway and Western pine, hemlock, tamarack, spruce and oak where they meet the requirements.

For flooring, roofing plank, trim and material where strength is not required, and low or medium humidity in the building does not demand special durability, a wider latitude in the selection is possible.

APPENDIX.

FORMULAS FOR DESIGN IN MILL CONSTRUCTION.

The design of the timber members of a mill construction type of building may be separated into the following divisions:

Floor and Roof Panels.
Girders and Beams.
Columns or Posts.

The various formulas used in the design of such members contain letters representing the quantities indicated below.

NOTATION FOR FORMULAS

$a = \frac{L}{d}$

b = Breadth of beam or girder in inches.
C = Strength of column in pounds per square inch of cross-section.
c = Allowable working compressive strength of timber in pounds per square inch with the grain.
D = Deflection in inches.
d = Depth of beam of girder, or least dimension of post in inches.
E = Modulus of elasticity of material in pounds per square inch.
f = Allowable unit bending stress in extreme fibers of section in pounds per square inch.
L = Unsupported length of post or column in inches.
l = Length of span of beam or girder in feet.
P = Load concentrated at any point on beam or girder in pounds.
s = Allowable unit shearing stress in direction of grain in pounds per square inch.
t = Thickness of underfloor, or roof plank in inches.
W = Total uniformly distributed load on beam or girder in pounds.
W_f = Total uniformly distributed load on a section of floor or roof plank 1 foot wide and "x" long.
x = Length of span between centers of girders or beams in feet.

Floor and Roof Panels

The minimum thickness of plank to be used in floors and roofs has been stated in the sections devoted to general construction and found in the earlier pages of this bulletin. The thickness needed to

support a given uniformly distributed floor or roof load may be found from the following formula:

$$t^2 = \frac{3 W_1 x}{4 f} \qquad \ldots\ldots (1)$$

To find the value of W_1, it will be necessary to know the kind of occupancy or the live load which is likely to be placed on the floor or roof, together with an allowance for the weight of the floor material itself. If sudden jars, vibration, or impact, is to be provided for, either a percentage may be added to the ordinary live loads, or the allowable working unit stresses may be decreased. The National Board of Fire Underwriters recommend that at least 25 percent be added to the stresses produced by live loads in structures carrying machinery, such as cranes, conveyors, printing presses, etc., to provide for effect of impact and vibrations.

The load which is likely to come upon a roof is made up of three parts; the dead load which consists of the weight of the roofing material and of roof structure; the snow load which may possibly come upon the roof, and a certain amount of load due to the wind. These must all be taken into account in making up the total. The element of wind load is not great on flat roofs, but the snow load may be quite an appreciable quantity. Table A gives average values for the snow load which may be present on buildings in different parts of the country.

The dead load may be found by estimating the quantity of material necessary to form the roof construction, and adding to it an amount to take care of the roof covering. Felt and gravel roofing of a 5-ply quality will weigh about 6 pounds per square foot of roof surface. Weights of timber and roofing materials will be found in Table B.

Live loads for various classes of occupancy may be estimated from Table C in case the local building ordinance does not specify a definite floor load for the class of building in question.

Table A.—Snow Loads in Different Localities.

Location.	Pounds per Sq. Ft. of Roof.
Southern and Pacific States	5
Central States	30
New England States	40
Northwestern States	45

Table B.—Average Weights of Timber and Roofing Materials.

TIMBER.

(Not over 15% moisture)

Kind of Wood.	Weight in Lbs. per Cu. Ft.
Cypress	29
Douglas Fir	32
Hemlock	26
Oak, Red	46
Oak, White	50
Pine, Cuban	40
Pine, Loblolly	40
Pine, Long Leaf Yellow	38
Pine, Norway	31
Pine, Short Leaf Yellow	32
Pine, White	24
Spruce	25
Tamarack	35

Flooring.		Weight in Lbs. per 1000 Ft. B. M.
Maple, Beech or Birch 13/16 in.x1½ in. or 2¼ in.		2100
Spruce	13/16 in. thick	2000
White Pine and Hemlock	" " "	1800
Yellow Pine	" " "	2250
Douglas Fir	" " "	2000

ROOFING MATERIAL.

	Weight Lbs. per Sq. Ft. of Roof.
Copper	1
Iron, Corrugated	1 to 4
Iron, Galvanized	1 " 3
Lead, Sheet	4 " 8
Shingles, Wood	2½
Slate	10
Tile, Fancy, laid in mortar	25 to 30
Tile, Plain	12
Tin, Painted	1
Zinc	1 to 2
Ready Roofing, 3-ply	1
Felt and Gravel Roofing, 4-ply	5½
Felt and Gravel Roofing, 5-ply	6

The following table, taken mainly from Report No. V., Boston Manufacturers' Mutual Fire Insurance Co., gives the approximate weights of merchandise. In designing storehouse floors it is important to provide for the greatest load which is likely to be placed in the building.

Table C.—Weights of Merchandise.

MATERIAL	MEASUREMENTS Floor Space Sq. Ft.	Cu. Ft.	WEIGHTS Gross	Per Sq. Ft.	Per Cu. Ft.
Wool					
In bales, Australia / " East India / " New Zealand	8.6	19.4	350	40	18
" South America	12.5	47.	1000	80	22
" Oregon fleece	7.5	33.	550	73	17
" California pulled	7.0	33.	480	70	15
" Texas scoured	7.0	33.	480	70	15
In bags, Domestic	15.5	18.	250	16	14
" scoured or noils	15.5	18.	100	6.4	5.5
Woolen Goods					
Case, Flannels	5.5	12.7	220	40	17
" " heavy	7.1	15.2	330	46	22
" Dress Goods	5.5	22.0	460	84	21
" Cassimeres	10.5	28.0	550	52	20
" Underwear	7.3	21.0	350	48	16
" Blankets	10.3	35.0	450	44	13
" Horse Blankets	4.0	14.0	250	63	18
Cotton					
Bale, Ginned	9.32	46.6	550	60	12
" Compressed	5.25	25.2	550	106	22
" Planters Compress Co.	1.80	5.4	250	139	47
" American Cotton Co.	2.60	7.8	270	104	35
" Egyptian	4.7	20.0	820	170	41
" Indian	4.7	20.0	860	176	43
Cotton Goods					
Bale Unbleached Jeans	4.0	12.5	300	72	24
Piece Duck	1.1	2.3	75	68	33
Bale Brown Sheetings	3.6	10.1	235	65	23
Case Bleached Sheetings	4.8	11.4	330	69	30
Case Quilts	7.2	19.0	295	41	16
Bale Print Cloth	4.0	9.3	175	44	19
Case Prints	4.5	13.4	420	93	31
Bale Tickings	3.3	8.8	325	99	37
Skeins Cotton Yarn	...	...	...	...	11
Carpet					
Roll of Carpet	4.1	10.9	129	31.5	11.8
Rug (with pole)	.44	4.	48	....	12.0
Silk					
Bale, Silk Cocoons	12.5	31.5	260	20.4	8.25
" " Frisons (average)	13.2	34.3	325	24.6	9.50
" Dressed Silk	12.	24.	400	33.4	16.6
" Raw Silk (average)	7.0	8.5	221	31.6	26.
" Spun Silk	5.	7.5	235	47.0	31.4
Case Broad Silk Cloth	6.5	10.4	180	27.7	17.3
" Ribbons	8.	16.	175	21.0	10.9
Jute, Etc.					
Bale, Jute	2.4	9.9	400	170	40
" Jute Lashings	2.6	10.5	450	172	43
" Manila	3.2	10.9	280	88	26
" Hemp	8.0	30.0	650	81	20
" Sisal	7.5	27.0	400	53	15
Burlaps, various packages	...	....	...	...	43
Jute Bagging	2.3	7.0	100	43	14

Table C.—(Continued).

MATERIAL	MEASUREMENTS Floor Space Sq. Ft.	Cu. Ft.	WEIGHTS Gross	Per Sq. Ft.	Per Cu. Ft.
Rags in Bales					
White Linen	8.5	39.5	910	107	23
" Cotton	9.2	40.0	715	78	18
Brown "	7.6	30.0	440	59	15
Paper Shavings	7.5	34.	500	68	15
Sacking	16.0	65.0	450	28	7
Woolen	7.5	30.0	600	80	20
Jute Butts	2.8	11.0	400	143	36
Spruce Chips, wet, tightly packed	...	....	...	...	18
" " " loosely "	...	....	...	...	14
" " dry	...	....	...	...	10
Paper					
16 x21, 30 lbs. Ledger	2.4	5.3	210	130	60
16 x21, 24 lb. Calendered Book	2.4	4.4	250	105	57
16 x21, 29 lb. Super-cal. "	2.4	4.3	300	125	70
18½x29, 26 lb. News	3.7	5.9	270	73	46
32 x42, No. 38 Straw Board	9.3	3.9	130	14	33
24 x31, 52 lb. Manila Wrapping	5.2	10.8	530	102	49
Sheets in bundles, with wood frames	5.4	4.0	120	22	30
" " without " "	6.3	4.2	140	22	33
Roll Newspaper	4.8	28.8	1200	250	41.0
Sulphite Pulp	...	....	...	...	17
Average Pile of Paper, in bundles	...	....	...	...	40
Tobacco					
Bale Sumatra wrapper	6.1	6.0	150	24.5	24.7
Hogshead of Tobacco	8.-13.4	36.-80.4	1000-2200	..	28
Grain					
Wheat in bags	4.2	4.2	165	39	39
" in bulk	...	....	...	...	44
" "	...	....	...	...	39
" " mean	...	....	...	...	41
Barrels Flour on side	4.1	5.4	218	53	40
" " " end	3.1	7.1	218	70	31
Corn in bags	3.6	3.6	112	31	31
Cornmeal in barrels	3.7	5.9	218	59	37
Oats in bags	3.3	3.6	96	29	27
Bale of Hay	5.0	20.0	284	57	14
Hay, Dederick Compressed	1.75	5.25	125	72	24
Straw, " "	1.75	5.25	100	57	19
Tow, " "	1.75	5.25	150	86	29
Excelsior, " "	1.75	5.25	100	57	19
Dye Stuffs, etc.					
Hogsheads Bleaching Powder	11.8	39.2	1200	102	31
" Soda Ash "	10.8	29.2	1800	167	62
Box Indigo	3.0	9.0	385	128	43
" Cutch	4.0	3.3	150	38	45
" Sumac	1.6	4.1	160	100	39
Caustic Soda in iron drum	4.3	6.8	600	140	88
Barrel Pearl Alum	3.0	10.5	350	117	33
Box Extract Logwood	1.06	.8	55	52	70
Barrel Lard Oil	4.3	12.3	422	98	34
Miscellaneous					
Rope	...	....	...	...	42
Box Tin	2.7	0.5	139	99	278
" Glass	...	....	...	...	60
Crate Crockery	9.9	39.6	1600	162	40
Cask "	13.4	42.5	600	52	14

Table C.—(Continued).

MATERIAL	MEASUREMENTS Floor Space Sq. Ft.	Cu. Ft.	WEIGHTS Gross	Per Sq. Ft.	Per Cu. Ft.
Bale Leather	7.3	12.2	190	26	16
" Goatskins	11.2	16.7	300	27	18
" Raw Hides	6.0	30.0	400	67	13
" " " Compressed	6.0	30.0	700	117	23
Bale Sole Leather	12.6	8.9	200	22	16
Pile " "	...	....	....	...	17
Barrel Granulated Sugar	3.0	7.5	317	106	42
" Brown "	3.0	7.5	340	113	45
Cheese	...	....	....	...	30
Pitch	...	....	....	...	72

ADDITIONAL WEIGHTS TAKEN FROM OTHER SOURCES ARE AS FOLLOWS:

Material	Weights per Cubic Foot of Space, lbs.
Building Materials	
Cement, Portland	100
Lime and Plaster	53
Lumber (See Table B)	
Hardware, etc.	
Door Checks	45
Hinges	54
Locks, in cases packed	31
Sash Fasteners	48
Screws	101
Wire, Insulated Copper, in coils	63
Wire, Galvanized Iron, in coils	74
Wire, Magnet, on spools	75
Drugs, Paints, Oil, etc.	
Blue Vitriol, in barrels	45
Glycerine, in cases	52
Linseed Oil, in iron drums	45
Linseed Oil, in barrels	36
Rosin, in barrels	48
Shellac, Gum	38
Soda, Silicate, in barrels	53
Sulphuric Acid	60
White Lead Paste, in cans	174
White Lead, dry	86
Red Lead and Litharge, dry	132
Groceries, Wines, Liquors, etc.	
Beans, in bags	40
Canned Goods, in cases	58
Coffee, Roasted, in bags	33
Coffee, Green, in bags	39
Dates, in cases	55
Figs, in cases	74
Flour, in barrels	40
Molasses, in barrels	48
Rice, in bags	58
Sal Soda, in barrels	46
Salt, in bags	70
Soap Powder, in cases	38
Starch, in barrels	25
Sugar, in cases	51
Sugar, in barrels	43
Tea, in chests	25
Wines and Liquors, in barrels	38

If a stiff floor with a limited deflection is desired, the following formula may be used to find the amount of deflection due to a uniformly distributed load on a floor of a given thickness, span between beams or girders, and kind of timber:

$$D = \frac{22.5\ W_1\ x^3}{E\ t^3} \qquad (2)$$

The value of D is commonly limited to 1/30 of an inch per foot of length of span where a plastered ceiling is to be used, or 1/25 of an inch per foot when ceilings are left without plastering.

Girders and Beams The design of the girders used in a structure will depend upon the manner in which the loads are supported by these girders. In mill construction buildings where laminated or standard mill floors are used, the load is distributed uniformly along the length of the girders; but in cases where intermediate beams supporting the floor extend from girder to girder, the loads are concentrated at the ends of the girder and at one or more equally spaced intermediate points. These different methods of support cause different effects in bending and deflection. Formulas for bending, shear, and deflection will be given for three of the common cases.

LOAD UNIFORMLY DISTRIBUTED.

Bending

$$d^2 = \frac{9\ W\ l}{f\ b} \qquad (3)$$

$$W = \frac{f\ b\ d^2}{9\ l} \qquad (4)$$

Shear

$$W = \frac{4}{3}\ b\ d\ s \qquad (5)$$

Deflection

$$D = \frac{270\ W\ l^3}{E\ b\ d^3} \qquad (6)$$

ONE CONCENTRATED LOAD AT CENTER OF GIRDER.

Bending

$$d^2 = \frac{18\ P\ l}{f\ b} \qquad (7)$$

$$P = \frac{f\ b\ d^2}{18\ l} \qquad (8)$$

Shear

$$P = \frac{4}{3} b\,d\,s \qquad (9)$$

Deflection

$$D = \frac{432\,P\,l^3}{E\,b\,d^3} \qquad (10)$$

TWO EQUAL CONCENTRATED LOADS AT THE THIRD POINTS OF GIRDER.

Bending

$$d^2 = \frac{24\,P\,l}{f\,b} \qquad (11)$$

$$P = \frac{f\,b\,d^2}{24\,l} \qquad (12)$$

Shear

$$P = \frac{2}{3} b\,d\,s \qquad (13)$$

Deflection

$$D = \frac{184.4\,P\,l^3}{E\,b\,d^3} \qquad (14)$$

To find the value of W, multiply the length of the girder between supports in feet by the distance between centers of floor panels on each side of the girder in feet. Then multiply this result by the dead and live load to be carried in pounds per square foot of floor area. This same mode of procedure may be used to find the amount of load on each intermediate beam, using the length of the beam and the half panels of floor on each side of the beam.

The amount of the concentrated load P at a given point due to intermediate beams supported by a girder may be found by taking one-half of the total uniform load on each intermediate beam supported at that point.

Both the bending and shear formulas should be tested in determining the proper size of a girder or beam, or the amount of load which may be carried safely. Stiffness is determined by the formulas for deflection.

The bearing area needed at the ends of girders may be found by dividing the reaction at a given end by the working compressive strength across the grain for the timber used. If

Table D.—Maximum Spans for Timber Mill Floors.

Fiber stress 1,200, 1,300, 1,500, 1,600 and 1,800 pounds per square inch; modulus of elasticity, 1,620,000 pounds per square inch.

The sum of the live load and the weight of the floor was used in calculating the spans.

In the line marked deflection is given the span which has a deflection of one-thirtieth of an inch per foot of span.

(Actual thickness)
Made of matched and dressed plank

Span in Feet.

Nominal Thickness	Actual Thickness	Fiber Stress Pounds Per Sq. In.	LIVE LOAD IN POUNDS PER SQUARE FOOT 50#	100#	125#	150#	175#	200#	225#	250#	275#	300#	350#	400#
3″	2⅝″	1200	13′ 8″	10′ 1″	9′ 1″	8′ 4″	7′ 9″	7′ 3″	6′10″	6′ 6″	6′ 3″	6′ 0″	5′ 7″	5′ 2″
″	″	1300	14′ 3″	10′ 6″	9′ 6″	8′ 8″	8′ 1″	7′ 7″	7′ 2″	6′10″	6′ 6″	6′ 3″	5′ 9″	5′ 5″
″	″	1500	15′ 4″	11′ 3″	10′ 2″	9′ 4″	8′ 8″	8′ 2″	7′ 8″	7′ 4″	7′ 0″	6′ 8″	6′ 2″	5′10″
″	″	1600	15′10″	11′ 8″	10′ 6″	9′ 7″	8′11″	8′ 4″	7′11″	7′ 7″	7′ 2″	6′11″	6′ 5″	6′ 0″
″	″	1800	16′ 9″	12′ 4″	11′ 2″	10′ 3″	9′ 6″	8′11″	8′ 5″	8′ 0″	7′ 8″	7′ 4″	6′ 9″	6′ 4″
″	″	Deflection	9′ 0″	7′ 4″	6′11″	6′ 6″	6′ 2″	5′11″	5′ 8″	5′ 6″	5′ 4″	5′ 2″	4′11″	4′ 9″
4″	3⅝″	1200	18′ 5″	13′ 8″	12′ 4″	11′ 5″	10′ 7″	10′ 0″	9′ 5″	9′ 0″	8′ 7″	8′ 3″	7′ 7″	7′ 2″
″	″	1300	19′ 2″	14′ 3″	12′11″	11′10″	11′ 0″	10′ 4″	9′10″	9′ 4″	8′11″	8′ 7″	7′11″	7′ 5″
″	″	1500	20′ 7″	15′ 4″	13′10″	12′ 9″	11′10″	11′ 2″	10′ 6″	10′ 0″	9′ 7″	9′ 2″	8′ 6″	8′ 0″
″	″	1600	21′ 3″	15′10″	14′ 4″	13′ 2″	12′ 3″	11′ 6″	10′11″	10′ 4″	9′11″	9′ 6″	8′10″	8′ 3″
″	″	1800	22′ 7″	16′ 9″	15′ 2″	13′11″	13′ 0″	12′ 2″	11′ 7″	11′ 0″	10′ 6″	10′ 1″	9′ 4″	8′ 9″
″	″	Deflection	12′ 3″	10′ 1″	9′ 5″	8′11″	8′ 6″	8′ 2″	7′10″	7′ 7″	7′ 4″	7′ 2″	6′10″	6′ 6″
5″	4⅝″	1200	22′10″	17′ 8″	15′ 7″	14′ 5″	13′ 5″	12′ 7″	11′11″	11′ 4″	10′10″	10′ 5″	9′ 8″	9′ 1″
″	″	1300	23′10″	17′11″	16′ 3″	14′11″	13′11″	13′ 1″	12′ 5″	11′10″	11′ 4″	10′10″	10′ 1″	9′ 5″
″	″	1500	25′ 7″	19′ 3″	17′ 5″	16′ 1″	15′ 0″	14′ 1″	13′ 4″	12′ 8″	12′ 2″	11′ 8″	10′10″	10′ 2″
″	″	1600	26′ 5″	19′11″	18′ 0″	16′ 7″	15′ 6″	14′ 7″	13′ 9″	13′ 1″	12′ 6″	12′ 0″	11′ 2″	10′ 6″
″	″	1800	28′ 0″	21′ 1″	19′ 1″	17′ 7″	16′ 5″	15′ 5″	14′ 7″	13′11″	13′ 4″	12′ 9″	11′10″	11′ 1″
″	″	Deflection	15′ 4″	12′ 9″	11′11″	11′ 3″	10′ 9″	10′ 4″	10′ 0″	9′ 8″	9′ 4″	9′ 1″	8′ 8″	8′ 4″
6″*	5⅝″*	1200	......	20′ 8″	18′ 9″	17′ 4″	16′ 2″	15′ 3″	14′ 5″	13′ 9″	13′ 2″	12′ 8″	11′ 9″	11′ 0″
″	″	1300	......	21′ 6″	19′ 6″	18′ 0″	16′10″	15′10″	15′ 0″	14′ 3″	13′ 8″	13′ 1″	12′ 2″	11′ 5″
″	″	1500	......	23′ 1″	21′ 0″	19′ 4″	18′ 1″	17′ 0″	16′ 1″	15′ 4″	14′ 8″	14′ 1″	13′ 1″	12′ 3″
″	″	1600	......	23′10″	21′ 8″	20′ 0″	18′ 8″	17′ 7″	16′ 7″	15′10″	15′ 2″	14′ 7″	13′ 6″	12′ 8″
″	″	1800	......	25′ 3″	23′ 0″	21′ 2″	19′10″	18′ 8″	17′ 8″	16′10″	16′ 1″	15′ 5″	14′ 4″	13′ 6″
″	″	Deflection	......	15′ 4″	14′ 5″	13′ 8″	13′ 0″	12′ 6″	12′ 1″	11′ 8″	11′ 4″	11′ 0″	10′ 6″	10′ 1″

*Use for laminated floors when made of 2x6 and 4x6 pieces.

(Courtesy Southern Pine Association, New Orleans, La.)

Table E.—Maximum Spans for Timber Laminated Floors.

Fiber stress 1,200, 1,300, 1,500, 1,600 and 1,800 pounds per square inch; modulus of elasticity, 1,620,000 pounds per square inch.

The sum of the live load and the weight of the floor was used in calculating the spans.

In the line marked deflection is given the span which has a deflection of one-thirtieth of an inch per foot of span.

(Actual thickness)

Made of planks on edge, laid close

Span in Feet.

Nominal Thickness	Actual Thickness	Fiber Stress Pounds Per Sq. In.	LIVE LOAD IN POUNDS PER SQUARE FOOT 100#	125#	150#	175#	200#	225#	250#	275#	300#	350#	400#
6"*	5½"*	1200	20' 3"	18' 4"	16'11"	15'10"	15' 1"	14' 1"	13' 5"	12'10"	12' 4"	11' 6"	10' 9"
"	"	1300	21' 1"	19' 1"	17' 8"	16' 5"	15' 8"	14' 8"	14' 0"	13' 4"	12'10"	11'11"	11' 2"
"	"	1500	22' 7"	20' 9"	18'11"	17' 8"	16'10"	15' 9"	15' 0"	14' 4"	13' 9"	12'10"	12' 0"
"	"	1600	23' 4"	21' 3"	19' 7"	18' 3"	17' 5"	16' 4"	15' 6"	14'10"	14' 3"	13' 3"	12' 5"
"	"	1800	24' 9"	22' 6"	20' 9"	19' 4"	18' 5"	17' 3"	16' 5"	15' 9"	15' 1"	14' 0"	13' 2"
"	"	Deflection	15' 0"	14' 1"	13' 4"	12' 9"	12' 3"	11' 9"	11' 5"	11' 1"	10' 9"	10' 3"	9'10"
8"	7½"	1200	26'10"	24' 6"	22' 8"	21' 2"	20' 0"	19' 0"	18' 1"	17' 4"	16' 7"	15' 6"	14' 7"
"	"	1300	27'11"	25' 6"	23' 7"	22' 1"	20'10"	19' 9"	18'10"	18' 0"	17' 4"	16' 1"	15' 2"
"	"	1500	30' 0"	27' 5"	25' 4"	23' 9"	22' 4"	21' 2"	20' 3"	19' 4"	18' 7"	17' 4"	16' 3"
"	"	1600	31' 0"	28' 3"	26' 2"	24' 6"	23' 1"	21'11"	20'10"	20' 0"	19' 2"	17'10"	16' 9"
"	"	1800	32'10"	30' 0"	27' 9"	26' 0"	24' 6"	23' 3"	22' 2"	21' 2"	20' 4"	19' 0"	17'10"
"	"	Deflection	20' 1"	19' 4"	17'11"	17' 2"	16' 6"	15'11"	15' 5"	15' 0"	14' 7"	13'11"	13' 4"
10"	9½"	1200									20'10"	19' 5"	18' 3"
"	"	1300									21' 9"	20' 3"	19' 1"
"	"	1500									23' 4"	21' 9"	20' 5"
"	"	1600									24' 1"	22' 5"	21' 2"
"	"	1800									25' 7"	23'10"	22' 5"
"	"	Deflection									18' 4"	17' 6"	16'10"
12"	11½"	1200											22' 0"
"	"	1300											22'11"
"	"	1500											24' 7"
"	"	1600											25' 4"
"	"	1800											26'11"
"	"	Deflection											20' 3"

*Use for 2½x6, 3x6 and 6x6 pieces, for 2x6 and 4x6 use table for mill floors.

(Courtesy Southern Pine Association, New Orleans, La.)

the load on the girder is uniformly distributed, the reaction will be one-half of the load. If the result obtained by dividing the area thus found by the width of the girder is less than 5 inches, this distance should be taken as the minimum length of support. Table F gives values for compressive strength across the grain for timber.

The unit bending stress (f) may be taken from Table F, according to the kind of timber used. This table gives working unit stresses for structural timbers used in dry locations, and is compiled in the main from material furnished by the Forest Products Laboratory, Madison, Wis. Other values of unit stresses for use in the various formulas will be found in this same table. Where definite unit stresses are stated in the building code of a city, such values should be used in all calculations, but Table F may be used with safety when no scheduled values are demanded.

Table F.—Working Unit Stresses for Structural Timbers Used in Dry Locations.

Species of Timber.	BENDING. Stress in Extreme Fiber Lbs.Sq.In.	BENDING. Horizontal Shear Stress Lbs.Sq.In.	COMPRESSION. Parallel to Grain "Short Columns" Lbs.Sq.In.	COMPRESSION. Perpendicular to Grain Lbs.Sq.In.
*Fir, Douglas				
Dense grade	1600	100	1200	350
Sound "	1300	85	900	300
Hemlock, Eastern	1000	70	700	300
Hemlock, Western	1300	75	900	300
Oak	1400	125	900	400
Pine, Eastern White	900	80	700	250
Pine, Norway	1100	85	800	300
*Pine, Southern Yellow,				
Dense grade	1600	125	1200	350
Sound "	1300	85	900	300
Spruce	900	70	600	200
Tamarack	1200	95	900	350

*NOTE: "The safe working stresses given in this table are for timbers with defects limited according to the sections on defects in the rules of the Southern Pine Association for Select Structural material. 'Dense' southern yellow pine and 'dense' Douglas fir should also conform to the other requirements of this rule. 'Sound' southern yellow pine and 'sound' Douglas fir require no additional qualifications, whereas the other species should, in addition to being graded for defects, have all pieces of exceptionally low density for the species excluded."

For reference to "dense" and "sound" classes, see footnote page 48.

Table G.—Average Values of Modulus of Elasticity for Various Species of Timber.

Species of Timber	Modulus of Elasticity in Bending Lbs. per Sq. In.
*Fir, Douglas	
Dense grade	1,600,000
Sound "	1,200,000
Hemlock, Western	1,400,000
Oak	1,300,000
Pine, Eastern White	1,300,000
Pine, Norway	1,400,000
*Pine, Southern Yellow	
Dense grade	1,600,000
Sound "	1,200,000
Spruce	1,000,000
Tamarack	1,200,000

*See note at bottom of page 61.

Since the values of maximum spans in Tables D and E for a deflection of one-thirtieth inch per foot of length are based upon a value of 1,620,000 pounds per square inch for the modulus of elasticity, the lengths given in the "deflection" lines of these tables should be multiplied by a constant when timber having another value of the modulus of elasticity is used.

The following constants are based upon the value of moduli of elasticity given in Table G:

1,600,000—use tables as they stand.
1,400,000—multiply lengths in tables by .952
1,300,000—multiply lengths in tables by .929
1,200,000—multiply lengths in tables by .904
1,000,000—multiply lengths in tables by .852

Posts or Columns Text-books on strength of materials contain many different formulas for determining the load to be carried by a column, or the fibre stress resulting from the application of a definite load. Some of these formulas are based upon theory, others upon experiment and a few upon a combination of theory and experiment. While the loads and stresses obtained from such formulas do not vary greatly, it is considered that those of an empirical nature which correspond with the results of actual tests are more to be depended upon.

Table H.—Table of Safe Loads in Pounds Uniformly Distributed for Timber Beams.

Limited by Resistance to Horizontal Shear Along the Neutral Axis.

(Actual size)

Nominal Size	Actual Size	Horizontal Shearing Stress in Pounds per Square Inch 100#	125#	150#	175#	200#
6 x10	5½x 9½	6966	8707	10449	12190	13932
8 x10	7½x 9½	9500	11875	14250	16625	19000
10 x10	9½x 9½	12032	15040	18048	21056	24064
6 x12	5½x11½	8432	10540	12648	14756	16864
8 x12	7½x11½	11500	14375	17250	20125	23000
10 x12	9½x11½	14566	18207	21849	25490	29132
12 x12	11½x11½	17632	22040	26448	30856	35264
6 x14	5½x13½	9900	12375	14875	17325	19800
8 x14	7½x13½	13500	16875	20250	23625	27000
10 x14	9½x13½	17100	21375	25650	29925	34200
12 x14	11½x13½	20700	25875	31050	36225	41400
14 x14	13½x13½	24300	30375	36450	42525	48600
6 x16	5½x15½	11366	14207	17049	19890	22732
8 x16	7½x15½	15500	19375	23250	27125	31000
10 x16	9½x15½	19634	24542	29451	34359	39268
12 x16	11½x15½	23766	29707	35649	41590	47532
14 x16	13½x15½	27900	34875	41850	48825	55800
16 x16	15½x15½	32032	40040	48048	56056	64064
6 x18	5½x17½	12834	16042	19251	22459	25668
8 x18	7½x17½	17500	21875	26250	30625	35000
10 x18	9½x17½	22166	27707	33249	38790	44332
12 x18	11½x17½	26834	33542	40251	46959	53668
14 x18	13½x17½	31500	39375	47250	55125	63000
16 x18	15½x17½	36166	45207	54249	63290	72332
18 x18	17½x17½	40832	51040	61248	71456	81664
20 x20	19½x19½	50700	63375	76050	88725	101400

(Courtesy Southern Pine Association, New Orleans, La.)

NOTE—To use table for values of the horizontal shearing stress less than 100 pounds per square inch, multiply the safe load in the 100 column by the ratio of the unit stress used to 100. For example: for 85 pounds per square inch, use .85 of the load in the 100 column.

Two formulas which are used widely are given below. The first is the result of work done under the supervision of the Division of Forestry, U. S. Department of Agriculture, and is what is known as a "curved line formula." The second is a formula proposed by Mr. Benjamin E. Winslow, Mem. Am. Soc. C. E., and is of the "straight line" type. The Winslow formula is used to quite a considerable extent in practice and is

incorporated in the Revised Building Ordinances of the City of Chicago.

U. S. Department of Agriculture, Division of Forestry Formula.

(Bulletin No. 12)

$$C=\frac{c\,(700+15a)}{(700+15a+a^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Winslow Formula.

$$\left.\begin{array}{l}\text{Unit Stress on Column Cross-Sec-}\\ \text{tion in Pounds per Square Inch}\end{array}\right\} = c\left(1-\frac{L}{80d}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Loads on Columns The amount of load carried by a given column on a top floor is found by adding together the end reactions brought to the bolster or cap by the girders or beams which support the roof and rest on the cap. In the case of uniformly distributed loads, these reactions are each one-half of the load carried by that particular beam or girder. If the loading is not symmetrical on a beam or girder, the end reactions may be found by the principle of moments.

Columns on lower floors carry a central load from the line of columns above, in addition to the loads from beams and girders supported by the cap of the column in question.

While it is not probable that all of the floors of a building will be loaded to the capacity of the allowable live load at any time, recommendations in regard to the percentage of this maximum load to use vary in the building codes of different cities.

A common recommendation in the case of buildings exceeding five stories in height is to use the full live load on the roof and top floor; for each succeeding lower floor the live load is reduced by 5 per cent until 50 per cent of the live load is reached, then these reduced loads are used for all remaining floors.

Another recommendation of a more conservative nature is to allow no reduction of live load in buildings where the assumed floor load is more than 120 pounds per square foot and is likely to be permanent, as in warehouses, shops, etc.

Eccentric loads on columns should be avoided if possible. If present, they should be treated by the use of formulas governing such loading.

Table I.—Timber Columns.

(Actual size)

Safe Loads in Tons of 2,000 Pounds Based on the Formula of the U. S. Department of Agriculture, Division of Forestry.
Square end bearing and symmetrically loaded.

For formula see page 64.

Nominal Size Inches	Actual Size Inches	Area Sq. In.	L/d	Length in Feet	Compression Parallel to the Grain. Pounds per Square Inch *1000
6x6	5½x5½	30¼	17.5	8	11.50
"	"	"	21.8	10	10.34
"	"	"	26.2	12	9.29
"	"	"	30.5	14	8.39
8x8	7½x7½	56¼	12.8	8	23.76
"	"	"	16.0	10	22.11
"	"	"	19.2	12	20.48
"	"	"	22.4	14	18.95
"	"	"	25.6	16	17.52
"	"	"	28.8	18	16.28
"	"	"	32.0	20	15.06
10x10	9½x9½	90¼	10.1	8	40.29
"	"	"	12.6	10	38.29
"	"	"	15.2	12	36.21
"	"	"	17.7	14	34.06
"	"	"	20.2	16	32.08
"	"	"	22.7	18	30.19
"	"	"	25.3	20	28.32
12x12	11½x11½	132¼	8.3	8	61.02
"	"	"	10.4	10	58.70
"	"	"	12.5	12	56.21
"	"	"	14.6	14	53.68
"	"	"	16.7	16	51.11
"	"	"	18.8	18	48.60
"	"	"	20.9	20	46.20
14x14	13½x13½	182¼	7.1	8	85.75
"	"	"	8.9	10	83.19
"	"	"	10.7	12	80.46
"	"	"	12.4	14	77.66
"	"	"	14.2	16	74.63
"	"	"	16.0	18	71.62
"	"	"	17.8	20	68.61
16x16	15½x15½	240¼	6.2	8	114.57
"	"	"	7.7	10	111.95
"	"	"	9.3	12	108.95
"	"	"	10.8	14	105.80
"	"	"	12.4	16	102.34
"	"	"	14.0	18	98.83
"	"	"	15.5	20	95.49
18x18	17½x17½	306¼	5.5	8	147.45
"	"	"	6.9	10	144.55
"	"	"	8.2	12	141.48
"	"	"	9.6	14	138.11
"	"	"	11.0	16	134.29
"	"	"	12.3	18	130.76
"	"	"	13.7	20	126.78

*To use table for a unit stress other than 1,000 lbs. sq. in., multiply value in table by the ratio of that unit stress to 1,000. For instance: for 1,200 lbs. sq. in., multiply values in table by 1.2; for 900 lbs. sq. in., multiply by .9.

Table J.—Timber Columns.

(Actual size)

Safe Loads in Tons of 2,000 Pounds Based on the Winslow Formula.
(Chicago Building Ordinance.)

Square end bearing and symmetrically loaded.

For formula see page 64.

Nominal Size Inches	Actual Size Inches	Area Sq. In.	L/d	Length in Feet	Compression Parallel to the Grain. Pounds per Square Inch *1000
6x6	5½x5½	30¼	17.5	8	11.82
"	"	"	21.8	10	11.01
"	"	"	26.2	12	10.18
"	"	"	30.5	14	9.35
8x8	7½x7½	56¼	12.8	8	23.64
"	"	"	16.0	10	22.50
"	"	"	19.2	12	21.37
"	"	"	22.4	14	20.25
"	"	"	25.6	16	19.12
"	"	"	28.8	18	18.00
"	"	"	32.0	20	16.87
10x10	9½x9½	90¼	10.1	8	39.42
"	"	"	12.6	10	38.03
"	"	"	15.2	12	36.55
"	"	"	17.7	14	35.20
"	"	"	20.2	16	33.84
"	"	"	22.7	18	32.32
"	"	"	25.3	20	30.85
12x12	11½x11½	132¼	8.3	8	59.51
"	"	"	10.4	10	57.53
"	"	"	12.5	12	55.78
"	"	"	14.6	14	54.10
"	"	"	16.7	16	52.24
"	"	"	18.8	18	50.58
"	"	"	20.9	20	48.93
14x14	13½x13½	182¼	7.1	8	82.93
"	"	"	8.9	10	81.10
"	"	"	10.7	12	79.27
"	"	"	12.4	14	76.96
"	"	"	14.2	16	74.97
"	"	"	16.0	18	72.90
"	"	"	17.8	20	71.07
16x16	15½x15½	240¼	6.2	8	110.84
"	"	"	7.7	10	109.00
"	"	"	9.3	12	106.15
"	"	"	10.8	14	103.86
"	"	"	12.4	16	101.44
"	"	"	14.0	18	99.05
"	"	"	15.5	20	96.86
18x18	17½x17½	306¼	5.5	8	142.55
"	"	"	6.9	10	139.90
"	"	"	8.2	12	137.54
"	"	"	9.6	14	134.75
"	"	"	11.0	16	132.11
"	"	"	12.3	18	129.74
"	"	"	13.7	20	127.09

*To use table for a unit stress other than 1,000 lbs. sq. in., see directions with Table I.

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(Continued)

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(*Continued*)